BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

HEARINGS

BEFORE THE

SPECIAL SUBCOMMITTEE ON RADIATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

EIGHTY-SIXTH CONGRESS

FIRST SESSION

ON

BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

JUNE 22, 23, 24, 25, AND 26, 1959

~~PART 1~~

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BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

MONDAY, JUNE 22, 1959

CONGRESS OF THE UNITED STATES,
SPECIAL SUBCOMMITTEE ON RADIATION,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D.C.

The subcommittee met, pursuant to notice, at 10:13 a.m., in Senate caucus room, Hon. Chet Holifield presiding.

Present: Representative Chet Holifield, chairman; Representatives Price, Van Zandt, Hosmer, Bates, Westland; and Senators Anderson, Hickenlooper, and Aiken.

Also present: James T. Ramey, executive director; John T. Conway, assistant director; George E. Brown, Jr., professional staff member; and Col. Richard T. Lunger, staff consultant; Dr. Carey Brewer, special consultant, Joint Committee on Atomic Energy.

Representative HOLIFIELD. The committee will be in order.

Today the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy is beginning a series of public hearings on the biological and environmental effects of a possible nuclear war.

The subcommittee has, for some time, realized that considerable confusion exists in the public mind as to the probable effects of nuclear weapons and their aftermath in the event of their employment in war.

We believe it is in the national interest to clear up this confusion, and we believe that clarification can be accomplished within the limits of unclassified information.

It was apparent from the hearings held by this subcommittee in 1957, that there is a very large practical difference between the problem created by the worldwide fallout coming from a program of testing nuclear weapons, and those that would result from the use of these weapons in an all-out war. Accordingly, the fallout problems associated with the testing of nuclear weapons were considered in a separate hearing early in May of this year. It is our purpose to investigate the problems of nuclear war in the present hearing.

The contrast between the two types of problems may be illustrated by a few examples. The test program involves the detonation of 170 megatons of total yield. Ninety-two megations of this were due to the fisssion yield. These detonations have occurred over a 10-year period. The problems we will consider in the present hearings involve the detonation of 3,950 megatons total yield, of which 1,976 megatons are fission yield, all detonated within 1 day.

The test program is conducted at remote places. Therefore, we are primarily concerned with material drawn into the stratosphere and the subsequent worldwide deposition of the radioactive debris. In the present hearings we are concerned with detonations in the midst of our cities and military bases. Therefore, we must consider the far more severe immediate and local effects which, under conditions of the test program, are dissipated harmlessly either over the ocean in the case of the Pacific tests, or over the desert, as in the Nevada tests.

The biological effects of the radioactive fallout resulting from the test program are so low that they must be evaluated on the basis of a theoretically estimated increase in the incidence of naturally occurring effects such as leukemia on the one hand or inherited effects such as abnormalities or stillbirths on the other. Under conditions of nuclear war, we are concerned with problems of immediate survival of people who may be subjected to radiation exposures as severe as those received by Dr. Slotin and Mr. Kelly of the Los Alamos Laboratory as a result of momentary but high intensity radiation.

The subcommittee and its staff have earnestly and diligently prepared an agenda and invited a distinguished and competent group of professional experts to be our witnesses.

For working purposes, we have prepared a hypothetical attack situation in which nuclear weapons of varying sizes have been placed on specified targets within the United States.

In addition, we have arbitrarily assigned a specific total weapon contribution to other areas of the Northern Hemisphere in order to calculate the worldwide fallout resulting from a hypothetical retaliatory attack by the United States, as well as from an enemy strike against our oversea bases.

To insure absolutely against the possibility of any direct or indirect inferences to existing classified war plans or stockpile information, the subcommittee, by design, refrained from requesting the support of any Department of Defense agencies in establishing this attack pattern. We have also refrained from using any classified information.

The attack pattern, including the sizes of weapons and their distribution on specific targets, has been carefully developed and represents assumptions that in our opinion are quite realistic. Other attack patterns of greater or lesser total megatonnage could have been planned. By the same token, extrapolations from this specific pattern can be made upward or downward.

The witnesses for these hearings have been chosen strictly on the basis of their competence and experience in the different fields of nuclear phenomena, with particular emphasis on nuclear weapons effects.

In the biomedical field we have chosen the men who have had the most experience in laboratory work on animals and actual experience in treating human beings who have been exposed to radiation, such as the Japanese survivors of Hiroshima and Nagasaki, and the Marshall Islands victims.

In the field of structural damage from blast and fire, we have chosen the experts who conducted or evaluated the "on the ground"

results of bomb tests at the Nevada and South Pacific testing grounds.

We turned to the experts in the U.S. Weather Bureau, backed by their worldwide organization, to establish for us a typical weather pattern for the date of our simulated attack.

The Office of Civil and Defense Mobilization has cooperated to the fullest extent in transferring our attack assumptions to maps, charts, and other visual aids. Their experience in computing structural damage by blast and fire as well as human casualties in the various "Operation Alerts" provided us with responsible and competent assistance in these vital fields.

We have utilized a mass of unclassified data from governmental and private sources on the effects of radiation. We are particularly indebted to Dr. Paul Tompkins and his associates of the U.S. Naval Radiological Defense Laboratory.

The resources of the Atomic Energy Commission, its personnel, and unclassified publications have been made available by Chairman McCone and have been of great value to the subcommittee and its staff.

It is the sincere purpose of the subcommittee to bring to the people of our country and the world the vital facts regarding the effects which a nuclear war would have on man and his environment. We believe that an informed and intelligent citizenry is the best insurance for the survival of free people.

Before I introduce our first witness, I would like to place in the record the outline of the hearings. Also a glossary of terms which I believe will be very helpful to the layman reading this publication.

(The material referred to follows:)

THE SPECIAL SUBCOMMITTEE ON RADIATION OF THE JOINT COMMITTEE ON ATOMIC ENERGY

OUTLINE FOR PUBLIC HEARINGS ON THE BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

June 22–26, 1959

GENERAL SCOPE OF THE HEARINGS

Purposes

To project as far as is technically possible the probable impact of the detonation of X000 megatons of nuclear weapons upon man and his environment both in the countries attacked and elsewhere on the planet. Competent witnesses in the biological and physical sciences will testify. The main emphasis of the hearings will be on the nuclear radiation effects of modern weapons.

Background

The subcommittee has, for quite some time, held the opinion that considerable confusion exists in the public mind as to the probable effects of nuclear weapons and their aftermath in the event of their employment in war. It is in the national interest to clarify this confusion insofar as possible within the limits of classification regulation.

Part of the apathy in the U.S. civil defense effort may be traced to ignorance of the true effects of radioactive fallout. In a time of national emergency an uninformed public could present a very real hazard to the Nation's security.

Limitations

No attempt will be made in this series of hearings to consider the overall impact of nuclear war upon the Nation's economy, specific recovery measures, or the degree of industrial recuperability in the long-range postattack situation.

Classification

Since the hearings will deal directly with the effects of nuclear weapons and their biological consequences, extreme care must be exercised to prevent the introduction of classified material.

The attack pattern

To assure a uniform basic problem it was decided that the attack pattern would be specified by the committee. This would provide a common basis from which independent analysis could then be made by each witness.

To absolutely insure against the possibility of any direct or indirect inferences to existing classified war plans or stockpile information, the committee, by design, refrained from requesting the support of any Department of Defense agencies in establishing this pattern or from using any classified information.

The pattern was developed under the following assumptions:

1. *Type of attack.*—A "limited" attack delivered against Western European bases and the continental United States by an aggressor employing any or all of the following weapons systems: (The term "limited" is meant to denote less than the maximum scale of attack but with greater dispersion of weapons than an attack directed only against strategic force bases.)

A. Long-range bombardment aircraft.
B. Submarine delivered missiles.
C. ICBM's.

For the purposes of computing global fallout a "limited" retaliatory attack against the aggressor homeland is used.

In making these assumptions the subcommittee has, in no manner attempted to "wargame" or explore the many factors involved in the problem of delivery or retaliation but is accepting for working purposes a net deliver in the "limited" types of attack involving the megatonnage indicated.

2. *Selection and location of targets.*—The targets in the continental United States were selected in accordance with those types used by OCDM in the conduct of their unclassified civil defense exercises and from published lists of military bases and Atomic Energy Commission installations. It was necessary to designate specific targets in order that realistic casualty and damage estimates could be prepared.

No attempt was made to pinpoint targets outside the continental United States. However, a total yield contribution in the Northern Hemisphere is necessary for long-range, worldwide fallout computation.

3. *Weapons.*—

A. Weapons spectrum: 10 megaton, 8 megaton, 3 megaton, 2 megaton, 1 megaton.

B. Total megaton contribution on continental United States: 1,453 megatons.

C. Continental U.S. target distribution:

Target	*Total megatons*
70 critical target areas	566
Industrial complexes.	
Communication centers.	
Population centers.	
112 Air Force installations	653
21 AEC installations	168
12 Army installations	24
5 Navy installations	28
4 Marine Corps installations	14

D. Time of attack: 12 m., Greenwich meridian time, on a typical mid-October day (assumes completed harvest in aggressor homeland).

E. Weather pattern: Actual pattern of October 17, 1958.

F. Height of burst: All weapons, "ground burst."

G. Fission, fusion ratio: 50–50 (all weapons).

H. Megaton contribution on Northern Hemisphere outside the continental United States: 2,500 megatons. (Includes: (*a*) Contribution on aggressor homeland; (*b*) contribution on oversea U.S. and allied targets.)

SCHEDULE

MONDAY, JUNE 22

Morning session: 10 a.m. Location: Caucus Room, Old Senate Office Building

I. Opening statement by Chairman Holifield

II. Basic Assumptions and Presentation of the Attack Pattern

A. Topics covered:
Overall situation
Type of attack
Time of attack
Weapons and yields involved
Target complexes

Witness: Mr. Eugene Quindlen, Office of Civil and Defense Mobilization.

III. Basic Effects of the Specified Weapons Used in the Hypothetical Attack Pattern

A. Topics covered:
Blast, thermal and initial radiation effects of the following weapons: 10 megaton, 8 megaton, 3 megaton, 2 megaton, 1 megaton

Witness: Dr. Frank Shelton, technical director, Defense Atomic Support Agency, Department of Defense

IV. Initial Radiation and Physical Effects of the Attack Against the Continental United States

A. Topics covered:
1. Radiation patterns, below 60,000 feet for the period: D-Day plus D plus 90 days.
2. The blast and thermal damage assessment, not to include human casualties.

Witness: Dr. Charles Shafer, Office of Civil and Defense Mobilization.

Afternoon session: 2 p.m.

Location: Caucus Room, Old Senate Office Building

V. The Worldwide Fallout Pattern

A. Topics covered:
1. A presentation of the worldwide fallout pattern resulting from the aggressor attack on the continental United States and United States and Allied bases in the Northern Hemisphere and the retaliatory attack on the aggressor homeland by the United States stategic forces.
2. The long-term hazard.

Witness: Dr. Lester Machta, U.S. Weather Bureau.

VI. Basic Properties and Effects of Radioactive Fallout

A. Topics covered:
1. Composition of debris:
(*a*) Radioactive elements produced by fission and fusion
(*b*) Effects on dose rates and total dose
(Note: Each single factor will be related to the time and distance from a single detonation)
2. Deviations from theory

Witness: Dr. Terry Triffet, Naval Radiological Defense Laboratory, San Francisco, Calif.

B. Effects of meteorology (wind and weather conditions)

Witness: Dr. Lester Machta, U.S. Weather Bureau

VII. Factors Modifying Behavior of Radioactive Deposits

A. Dosimetry of Direct Radiation from Nuclear Weapons

Witness: Dr. G. S. Hurst, Health Physics Division, Oak Ridge National Laboratory

TUESDAY, JUNE 23

Morning session: 10 a.m.

Location: Caucus Room, Old Senate Office Building

B. Normal weathering and the effects of terrain (mountains and hills; ravines and gullies; vegetation, etc.)

Witness: Mr. Myron Hawkins, Deputy Director, Civil Defense Research Project, University of California

VIII. Round Table Panel Discussion on the Basic Properties and Effects of Radioactive Fallout

Panel Membership:

Dr. Paul Tompkins, Naval Radiological Defense Laboratory
Dr. Terry Triffet, Naval Radiological Defense Laboratory
Mr. Myron Hawkins, Project Civil
Mr. Joe Deal, U.S. Atomic Energy Commission
Mr. Charles Shafer, Office of Civil Defense Mobilization
Dr. Lester Machta, U.S. Weather Bureau
Dr. Ralph E. Lapp, nuclear physicist

Afternoon session: 2 p.m.

Location: Caucus Room, Old Senate Office Building

IX. Biological Effects

A. Humans:

Heat and light (thermal burns and flash effects on the eyes)

Witnesses: Dr. William T. Ham, Jr., Department of Biophysics, Medical College of Virginia, Richmond, Va.; Dr. George Mixter, Jr., associate professor of surgery, New York University Post Graduate School of Medicine

Radiation

(*a*) Acute effects

Witness: Dr. Payne S. Harris, Health Research Division, Los Alamos Scientific Laboratory

(*b*) Effects from protracted exposures

(1) Experimental

Witness: Col. J. E. Pickering, USAF, School of Aviation Medicine, Randolph Air Force Base, Tex.

WEDNESDAY, JUNE 24

Morning session: 10 a.m.

Location: Room P-63, The Capitol

(2) Humans

Witness: Newell, Dr. Robert R., U.S. Naval Radiological Defense Laboratory

Blast effects

Witness: Dr. Clayton S. White, Director of Research Lovelace Foundation, Albuquerque, N. Mex.

Radiation

(*a*) Skin (Beta Burns)

Witness: Dr. Victor P. Bond, Medical Research Center, Brookhaven National Laboratory

(*b*) Acute effects of ingestion and inhalation of fallout debris

(1) Ingestion

Witness: Dr. Gordon Dunning, Division of Biology and Medicine, U.S. Atomic Energy Commission

(2) Inhalation

Witness: Dr. Stanton Cohn, Brookhaven National Laboratory

(*c*) Measures of body burdens of fission products

Witness: Lt. Col. James B. Hartgering, M.D., U.S. Army, Walter Reed Army Medical Center, Washington, D.C.

Afternoon session: 2 p.m.

Location: Room P–63, The Capitol

(*d*) Somatic and Genetic Effects
(1) Somatic
Witness: Dr. Hardin Jones, Donner Laboratory, University of California, Berkeley, Calif.
(2) Genetic
Witness: Dr. James V. Neel, Department of Human Genetics, University of Michigan Medical School, Ann Arbor, Mich.

X. Panel on Biological Effects

Panel members:
Dr. Paul C. Tompkins, Naval Radiological Defense Laboratory
Dr. Robert R. Newell, Naval Radiological Defense Laboratory
Dr. Gordon Dunning, U.S. Atomic Energy Commission
Dr. Hardin Jones, Donner Laboratory
Dr. Payne S. Harris, Los Alamos Scientific Laboratory
Dr. James V. Neel, University of Michigan
Lt. Col. Gerald MacDonnel, Office of The Surgeon General, Dept. of the Army
Col. John E. Pickering, USAF, School of Aviation Medicine
Dr. William T. Ham, Jr., Medical College of Virginia

THURSDAY, JUNE 25

Morning session: 10 a.m.

Afternoon session: 2 p.m.

Location: Room P–63, The Capitol

XI. Casualty Estimates (Human Beings in the United States)

A. Under conditions of attack pattern outlined:
1. Casualties from blast and fire
2. Immediate casualties from acute radiation
Witness: Mr. Eugene Quindlen, Office of Civil and Defense Mobilization
B. Delayed casualties from radiation
Witness: Dr. Gordon Dunning, Division of Biology and Medicine, U.S. Atomic Energy Commission

XII. Survival Measures (Technical Considerations) and Their Effects on Saving Human Lives

A. Topics covered:
1. Population shelters:
(a) Protection available from existing shelters
(b) Special shelters
2. Protective measures for emergency supplies and equipment (food, medical, water, essential equipment, etc.)
Witness: Mr. W. E. Strope, Naval Radiological Defense Laboratory

Location: Room P–63, The Capitol

XIII. Environmental Contamination

A. Effect on Animals
Witness: Dr. Bernard F. Trum, Director, Animal Research Division, Harvard University Medical School, Boston, Mass.
B. Effect on Food Supply
1. Soils and crops
Witness: Dr. Robert T. Reitemeirer, Department of Agriculture, Washington, D.C.
2. Processed foods
Witnesses: Dr. Edwin P. Laug, Bureau of Biological and Physical Sciences, Food and Drug Administration; Mr. Shelbey B. Gray, Bureau of Program Planning and Appraisal, Food and Drug Administration

C. Long-term Effects on Environment
  1. Experimental
    Witness: Dr. Kermit Larsen, UCLA, atomic energy project, Los Angeles, Calif.
  2. Long-range Implications
    Witness: Dr. John Wolfe, Division of Biology and Medicine, U.S. Atomic Energy Commission

FRIDAY, JUNE 26

Morning session: 10 a.m.

Location: Room P-63, The Capitol

XI. Casualty Estimates—Continued
  Witness: Quindlen, Eugene, Office of Civil and Defense Mobilization

XIV. Strategic Aspects of Survival Measures
  Witness: Mr. Herman Kahn, Center of International Studies, Princeton University

XV. Emergency Protection Measures
  A. Topics covered:
    1. Warning devices
    2. Communications
    3. Monitoring
  Witness: Dr. Willard F. Libby, Commissioner, U.S. Atomic Energy Commission

XVI. Panel Discussion
  A. Topics to be covered:
    1. Reliability of Estimates
    2. Strategic Implications
      (Role in Deterrence)
  Panel members:
    Dr. Paul Tompkins, Naval Radiological Defense Laboratory
    Dr. Willard F. Libby, Commissioner, USAEC
    Mr. Robert Corsbie, Director, Civil Effects Group, USAEC
    Mr. Herman Kahn, Princton University
    Mr. W. E. Strope, Naval Radiological Defense Laboratory

GLOSSARY OF TERMS

Alpha particle—A fundamental particle resulting from radioactive decay, consisting of 2 protons and 2 neutrons and possessing kinetic energy or energy of motion. The energy of an alpha particle is measured in million electron volts. Abbreviated: Alpha.

Average or mean life—The actual life of any particular radioactive atom, can have any value between zero and infinity. The average or mean life of a large number of atoms, however, is a definite quantity and is equal to 1.44 times the half life.

Beta particle—A fundamental particle resulting from radioactive decay. It consists of a negatively charged electron possessing kinetic energy or energy of motion. Beta particle energies range from kilo electron volts to million electron volts. Abbreviated: Beta.

Biological half life — The biological half life of any element or radioactive nuclide is the time interval required to reduce the number of atoms present in the body to half of their initial value. The biological half life does not include the radioactive half life of a radioactive element.

Curie — That quantity of a radioactive nuclide disintegrating at the rate of 3.70 by 10^{10} atoms per second or 2.22 by 10^{12} atoms per minute. Abbreviated: c.

Micromicrocurie — 1 million millionth of a curie or that quantity of a radioactive nuclide disintegrating at the rate of 3.7 by 10^{-2} atoms per second or 2.22 atoms per minute. Abbreviated: $\mu\mu$c.

Millicurie — 1 thousanth of a curie or the quantity of a radioactive nuclide distintegrating at the rate of 3.70×10^{7} atoms per second or 2.22×10^{9} atoms per minute. Abbreviated: Mc.

Megacurie — 1 million curies or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{16} atoms per second or 2.22×10^{18} atoms per minute.

Dose — The radiation delivered to a specified area or volume or to the whole body.

Effective half life — The time required for a radioactive element in the body to be diminished to half of its value as a result of the combined action of radioactive decay and biological elimination.

Electron volt — A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Larger multiples of the electron volt are frequently used, viz, Kev. for thousand or kilo electron volts; Mev. for million electron volts; and Bev. for billion electron volts.

Erg — Unit of work or energy done by a unit force acting through unit distance. The nuclear unit of work or energy is the Mev. which is equal to 1.6×10^{-6} ergs.

Gamma ray — Electromagnetic radiation resulting from radioactive decay. Gamma rays have no mass and no charge, but have energy which ranges from Kev. to Mev.

Half life — The half life of a radioactive atom is the time interval over which the chance of survival is exactly one-half. In any large number of disintegrating radioactive atoms half of the atoms present at any time will decay during one-half life. The half life for a particular nuclide is given by

$$t_{1/2} = \frac{0.693}{\lambda}$$

where λ is a constant for each nuclide.

Biological half life — The biological half life of any element or radioactive nuclide is the time interval required to reduce the number of atoms present in the body to half of their initial value. The biological half life does not include the radioactive half life of a radioactive element.

Effective half life — The time required for a radioactive element in the body to be diminished to half of its value as a result of the combined action of radioactive decay and biological elimination.

Radioactive half life — The half life of a radioactive atom is the time interval over which the chance of survival is exactly one-half. In any large number of disintegrating radioactive atoms half of the atoms present at any time will decay during one-half life. The half life for a particular nuclide is given by

$$t_{1/2} : \frac{0.693}{\lambda}$$

where λ is a constant for each nuclide.

Stratospheric half life — The time interval required to reduce the activity present in the stratosphere to half by removal from the stratosphere to the troposphere. Stratospheric half life does not include radioactive half life of any of the radioactive nuclides.

Isotope — An isotope is the individual species of atoms in an element having a certain mass. For example: U^{233}, U^{234}, and U^{235} are isotopes of uranium.

Kilo electron volt — See electron volt.

Mean or average life — The actual life of any particular radioactive atom can have any value between zero and infinity. The mean or average life of a large number of atoms, however, is a definite quantity and is equal to 1.44 times the half life.

Megacurie — 1 million curies or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{16} atoms per second or 2.22×10^{18} atoms per minute.

Micromicrocurie — 1 million millionth of a curie or that quantity of a radioactive nuclide disintegrating at the rate of 3.7×10^{-2} atoms per second or 2.22 atoms per minute. Abbreviated: $\mu\mu c$.

Millicurie — 1 thousandth of a curie or the quantity of a radioactive nuclide distintegrating at the rate of 3.70×10^{7} atoms per second or 2.22×10^{9} atoms per minute. Abbreviated: Mc.

Million electron volts — See electron volt.

Nuclide — A nuclide is the individual species of atoms in an element having a certain mass and a specific energy content. Therefore, more than 1 nuclide may compose an isotope. For example, Ba–137m (radioactive) and Ba–137 (stable) are nuclides of the same isotope.

Rad — The unit of absorbed dose, which is 100 ergs per gram. The rad is a measure of the energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. It is a unit that was recommended and adapted by the International Commission on Radiological Units at the Seventh International Congress of Radiology, Copenhagen, 1953.

Relative biological effectiveness — The ratio of gamma or X-ray dose to the dose that is required to produce the same biological effect by the radiation in question.

REM — Roentgen equivalent man: that quantity of any type ionizing radiation which when absorbed by man produces an effect equivalent to the absorption by man of 1 roentgen of X- or gamma radiation (400 KV).

REP — Roentgen equivalent physical: the amount of ionizing radiation which will result in the absorption in tissue of 83 ergs per gram. (Recent authors have suggested the value of 93 ergs per gram.)

Stratosphere — The upper portion of the atmosphere, above (11 km), more or less (depending on latitude, season, and weather) in which temperature changes but little with altitude and clouds of water never form, and in which there is practically no convection.

Stratospheric half life — The time interval required to reduce the activity present in the stratosphere to half by removal from the stratosphere to the troposphere. Stratospheric half life does not include radioactive half life of any of the radioactive nuclides.

Strontium unit — Formerly sunshine unit. 1 thousandth of the maximum permissible body level of Sr–90. It is equal to 1 micromicrocurie per gram of calcium.

Tropopause — The imaginary boundary layer dividing the upper part of atmosphere, the stratosphere, from the lower part, the troposphere. The tropopause normally occurs at something like 35,000 to 55,000 feet altitude, although it depends on season and location.

Troposphere — All that portion of the atmosphere below the stratosphere. It is that portion in which temperature generally rapidly decreases with altitude clouds form, and convection is active.

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Representative HOLIFIELD. As our first witness I shall call on Mr. Eugene Quindlen, of the Office of Civil and Defense Mobilization, to state for the record the basic assumptions drawn up by the subcommittee and used by the OCDM in their damage assessment for these hearings.

At a later point in the hearings the OCDM will be asked to present the results of their computations with respect to the structural damage and casualties which would be caused by the hypothetical attack presented by the subcommittee.

Representative HOLIFIELD. Mr. Quindlen, we are happy to have you before us this morning as the witness from OCDM and the chairman wishes to thank you on behalf of the Joint Committee on Atomic Energy for your cooperation during some 6 weeks we have been working to get this program in shape for presentation, and we wish to thank you personally for attending this morning. You may proceed.

STATEMENT OF EUGENE QUINDLEN,[1] OFFICE OF CIVIL AND DEFENSE MOBILIZATION

Mr. QUINDLEN. Thank you, Mr. Chairman, and our thanks to the members of the committee.

We are very pleased to be here because we believe, as you do, that people must be informed about the nature of the threat and about the actions which they take to meet the threat.

Informing the American people is a major aim of the Office of Civil and Defense Mobilization. We believe that an informed public—and we try our best to inform the public—will take the action which is necessary. We welcome any additional opportunity to bring this matter to public attention.

The attack to be considered during these hearings was specified by the committee. The Office of Civil and Defense Mobilization did not participate in the formulation of the attack pattern, but did do the assessment of the effects of this attack upon the United States.

The attack (Chart No. 1) consists of 263 weapons delivered on 224 targets in the United States. This is a net attack representing the number of weapons reaching the United States rather than the gross number with which the aggressor force might have started.

The total megatonnage of the attack was 1,446. The weapons used were 1 megaton in size—that is the equivalent of 1 million tons of TNT—2 megatons, 3 megatons, 8 megatons and 10 megatons.

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[1] Eugene J. Quindlen is the Deputy Assistant Director for Federal, State, and Local Plans of the Office of Civil and Defense Mobilization. He has responsibility for advice and guidance to cities, States, and Federal agencies on civil-defense operational planning, for the program of providing matching funds to States and localities, for the surplus-property program of OCDM and for operational analysis.

Mr. Quindlen has held staff positions with OCDM and its predecessor agency, FCDA, since March 1951. He has participated in all phases of the planning of FCDA programs and has held responsible staff positions in the annual civil-defense exercise, Operation Alert. Previous assignments within FCDA include Deputy Assistant Administrator of the Planning Staff and Assistant Administrator of Operations.

Mr. Quindlen has 17 years of service with the Federal Government, including 4 years of active duty as a medical administrative officer with the Army Medical Department. He was also employed by the Veterans' Administration and had departmental and field experience in the Federal Security Agency, which is now the Department of Health, Education, and Welfare.

Mr. Quindlen holds a B.A. degree from LaSalle College, an M.A. degree in educational psychology and statistics from Fordham, and a law degree from Georgetown University. His graduate work included an assistantship at Fordham University and research in the use of machine methods in the handling of mass statistics.

I have a chart (table 1) to which I would like to refer, Mr. Chairman, which summarizes these weapon sizes. As I indicated, there were 263 weapons used for a total weight of 1,446 megatons; 60 of these weapons were 10-megaton size for a total of 600. This chart illustrates the distribution of the other weapon sizes. There were 74 of 8 megatons for a total of 592, and, as you will see, there was a large weight in the higher weapons of 8 and 10 megatons reducing to 37 of the 2-megaton weapons and 48 of the 1 megaton, for a total attack of 1,446 megatons.

The next chart (table 2) shows the distribution by target; 111 of the targets were Air Force installations. Total weight 645 megatons. The size of the weapons used on Air Force installations varied; 71 of the targets were critical target areas. By this we mean concentrations of population and industry. They contain about 68 million of the country's population. One hundred and ten weapons were used against these areas for a total weight of 567 megatons. I will leave this chart up while I talk further, Mr. Chairman.

(The charts referred to are as follows:)

TABLE 1.—*Weight of the attack*

Size of weapon (megatons)	Number used	Weight of attack (megatons)
10	60	600
8	74	592
3	44	132
2	37	74
1	48	48
Total	263	1,446

TABLE 2.—*Targets of the attack*

Number and type of target	Number of weapons	Weight (megatons)
111 Air Force installations	111	645
71 Critical target areas	110	567
21 AEC installations	21	168
12 Army installations	12	24
5 Navy installations	5	28
4 Marine Corps installations	4	4
224, total	263	1,446

Representative HOLIFIELD. Mr. Quindlen, I think it would be well to bring out at this point the fact that the two bombs used over the Japanese cities were approximately 20,000 tons of TNT equivalent.

Mr. QUINDLEN. Yes, in that general area.

Representative HOLIFIELD. In that general area?

Mr. QUINDLEN. Yes.

Representative HOLIFIELD. So, when we talk about a megaton, we are talking about a million tons, and then we have to, in our mind, compare that with 20,000 tons which destroyed a city of some 100,000 inhabitants in Japan.

Mr. QUINDLEN. Yes, sir; that is true.

About 39 percent of the weapons used were used against the industrial and population areas, about 12 percent were used against Atomic

Energy Commission facilities, and about 49 percent or half were used against military installations.

All weapons used were assumed to be ground-burst weapons, that is the weapons were detonated with the fireball touching the ground, thereby causing fallout over considerable distances downwind from the detonation.

The attack occurred, according to the situation established by the committees at 12 noon Greenwich time on a typical mid-October day.

The Office of Civil and Defense Mobilization was requested by the committee to prepare an assessment of the effects of this attack upon human beings in the United States and upon dwellings. The weapons selected by the committee were placed at or near the targets designated by the committee, using a statistical method for random bombing errors.

No evacuation was assumed, but for purposes of computation of fallout casualties, it was assumed that the population would take advantage of the fallout protection provided by existing buildings. The protection factors used ranged from a reduction to one-half for those afforded worst protection, to a reduction to one two-hundredth for those afforded best protection. It is possible that some groups of the population would have worst protection than one-half and some better protection than one two-hundredth, but the differences in the national totals would not, in our opinion, be significant.

The damage assessment was computed by OCDM using a machine method which it employs in its own operations research. The basic device in the system is a large high-speed electronic computer. In making an estimate by this method, it is necessary to know three things: first, the location of the resource such as population, against which damage will be calculated; second, the blast and radiation effects of nuclear weapons; and third, the attack information, including ground zero, size of the weapon, and the height of burst.

Under the assessment system which was used, records of the location of the Nation's resources are stored on magnetic tapes. A locator system is used based on the UTM system, that is the universal transverse mercator system first developed for military purposes.

About 24,000 locations throughout the United States are noted in the machine using the UHM locations so that any one of these points can be measured in its relationship to the point of detonation of any weapon.

The data which we used on the estimated effects of nuclear weapons on people and things are those which have been developed by the various agencies of Government. The estimate which OCDM made of this attack is concerned with the effects on people and on dwellings for individual metropolitan areas, for States, for OCDM regions and for the United States as a whole. Thank you, Mr. Chairman.

Representative HOLIFIELD. Does that conclude your statement, Mr. Quindlen?

Mr. QUINDLEN. Yes, sir.

Representative HOLIFIELD. At this point, I would like to place in the record a letter, under date of June 20, directed to the chairman

of the subcommittee by Lt. Gen. James M. Gavin, U.S. Army, retired, former Deputy Chief of Staff for Research and Development.

DEAR MR. HOLIFIELD: I have examined the theoretical nuclear attack pattern that is to be considered by your committee in the hearings beginning June 22, 1959. I consider your assumptions to be entirely realistic and well within the capabilities of a potential aggressor.

JAMES M. GAVIN,
Lieutenant General (Retired).

Are there any questions of the witness?

If not, you are excused, sir.

Mr. QUINDLEN. Thank you, sir.

Representative HOLIFIELD. Our next witness will be Dr. Frank Shelton, Technical Director, Defense Atomic Support Agency of the Department of Defense. Dr. Shelton will give a presentation of the effects of the different-sized weapons used.

STATEMENT OF DR. FRANK SHELTON,[1] TECHNICAL DIRECTOR, DEFENSE ATOMIC SUPPORT AGENCY, DEPARTMENT OF DEFENSE

Dr. SHELTON. Mr. Chairman, it is a pleasure to appear before the committee. I have a few figures that we will have to put on the easel, but I will begin because they are used partially down in the text.

The effect of a nuclear war is the sum of the effects of the weapons employed against the individual targets. The individual weapon's effects thus form the building blocks for the sum of the effects. It is generally true that the effects of blast, thermal radiation, and prompt nuclear radiation (emitted directly from the exploding bomb) will not overlap the same areas with important effects unless two or more bombs are detonated rather close together on a single target. Local fallout from surface bursts is about the only weapon effect that can be expected to have overlapping effects from one bomb to another and this is especially true in the downwind directions.

Thus, the total damage to the country from blast, thermal radiation, and prompt nuclear radiation is essentially the sum of the individual effects on the individual targets.

In the case of fallout one often has to add the effects of one bomb on another in their common fallout areas. Finally, worldwide fallout is the sum of each of the individual weapons contribution.

In summarizing the various effects, I would like to draw into perspective, in some small measure, the relatively large areas and are also likely to be involved by the other effects. As an example, the lethal fallout area giving about 700 rem in 48 hours——

Representative HOLIFIELD. Will you please explain rem?

Dr. SHELTON. Can I hold that? It is in the text, if you will allow me to wait until we get to that point.

Representative HOLIFIELD. All right.

Dr. SHELTON. An accumulation of about 700 rem in 48 hours for an unshielded person can be expected to occur over about 1,500 square

[1] Technical director of the Defense Atomic Support Agency. He has been active in the atomice energy field since 1952. During the spring of 1955, he served as technical adviser to the military effects test group at Operation Teapot, and in 1953 participated in Upshot-Knothole. Dr. Shelton was born in 1924. He received his bachelor of science, master's and doctor of philosophy degrees, all in physics, from the California Institute of Technology. Prior to joining the Defense Atomic Support Agency, Dr. Shelton was with the Sandia Corp. in the weapons-effects field.

miles from a 10 megaton surface burst (50 percent fission); that is, an area that could be about 100 miles long and about 17 miles at the maximum width.

Few people appreciate the fact that, for the same bomb, second degree burns on the exposed face and hands and the ignition of fine kindling fuels can encompass an area of about 25 miles radius or about 2,000 square miles in the immediate vicinity and perhaps dense population of the target area. That is, this thermally affected area could be substantially larger than that of the lethal fallout area. And, if there is some shielding of personnel in the downwind fallout areas, the thermal effects area would certainly be the larger of the two.

Fallout and its potentially lethal areas are imporant, but so are the areas of the other effects: the pendulum of interest has swung to fallout and there is some tendency to overlook the very important other effects. Your expert witnesses in blast, thermal radiation, and prompt nuclear radiation also have an important part of the story. The results produced in Japan by the two nominal yield bombs were from only blast, thermal radiation and prompt nuclear radiation. There was no local fallout involved in the nearly 400,000 casualties in the tale of those two cities.

In discussing the effects of a large yield detonation it seems pertinent to:

I. Describe what happens when a nuclear detonation occurs; that is, how the blast, radiant heat, prompt nuclear radiation, and fallout are produced.

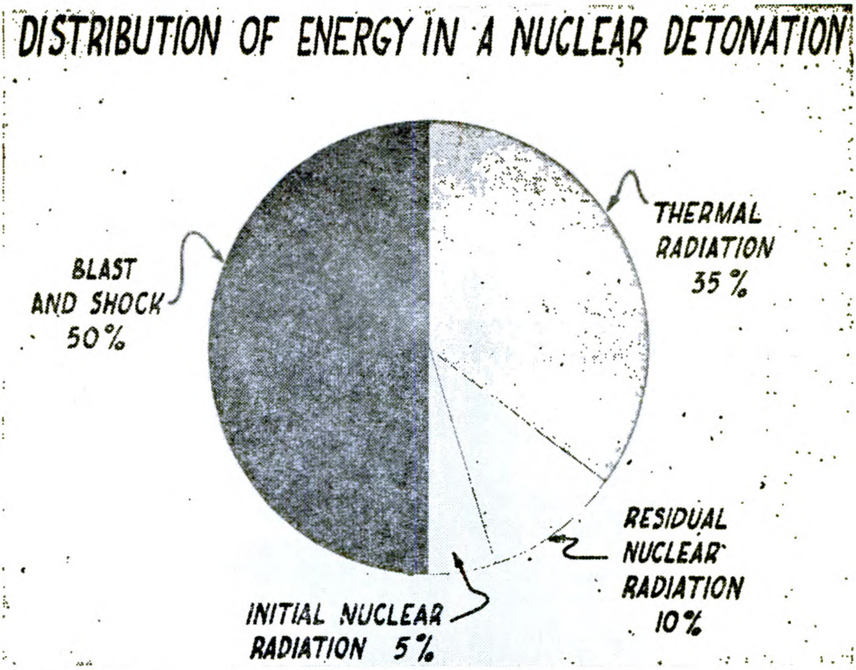
II. Next, I would like to describe very briefly the main differences in an airburst and a surface burst. I realize that the hypothetical attack assumed for these hearings utilizes surface bursts; however, a few words about airbursts does not appear out of place.

III. Finally, I would like a summarize the various weapons effects by relating the distances at which certain effects can be expected to produce a given level of damage to man or structures.

I. DESCRIPTION OF A NUCLEAR EXPLOSION

At the moment of detonation, a tremendous amount of energy is released in an extremely short time and small space. This rapid release of energy heats the bomb material and surrounding air to temperatures of several hundred thousand degrees, forming a luminous sphere of hot gases called the "fireball." The expansion of the air heated by the nuclear detonation causes the formation of a shock wave. At rather close distances to the burst, the shock wave is extremely strong and shocks the air to conditions such that it is radiant—that is, glows—and the fireball continues to grow in size. About 35 percent of the total energy of the explosion is given off as radiant thermal energy (see fig. 1) or heat, in essentially the same way that the sun radiates heat, although in the case of a bomb it is delivered very rapidly.

FIGURE 1



In a short time, the blast wave is no longer of sufficient strength to render the air luminous, and the blast wave breaks away from the fireball and continues to move outward—spherically for an airburst, or as a hemisphere for a surface burst. Another 50 percent of the total bomb energy is contained in the blast wave (see fig. 1).

Thirty-five percent for thermal energy and 50 percent for blast are good values for surface bursts or near surface bursts, or low air bursts. As one goes up in altitude—and I am only saying this because there has been recently some information from the Johnston Island shots, and I might clarify that—as one goes up in altitude one would expect a larger percentage of thermal radiation and a lower percentage of blast and essentially the same initial and residual radiation. There is an increase in thermal radiation at the expense of blast as the altitude of the burst increases.

The blast wave travels many times the speed of sound. About 5 percent of the total energy is given off within the first minute as prompt nuclear radiation (see fig. 1)—gamma rays, much like X-rays and certain elementary particles—neutrons, alpha particles, and beta particles. The remaining 10 percent of the total energy is released from the radioactive fission products over long periods of time.

As the fireball rises after the explosion, the gases cool rapidly and condense to the familiar radioactive cloud. If the weapon is burst at or near the surface, a large amount of material is sucked up into the column and cloud, and part of it is vaporized along with the radioactive fission fragments. As the vapors cool and condense, many of the soil particles either capture some of the radioactive fission products

inside of them, or through adhesion to their surface. The heavier particles fall back to earth quite quickly, but the lighter ones are carried up in the cloud, and then carried by the winds in the upper atmosphere, where they slowly fall back to earth for several hundred miles from ground zero to form the local fallout.

In the case of a large yield surface burst approximately 80 percent of the fission products fall back to the ground to form the local fallout pattern. The remaining 20 percent of the fission products from a surface burst and essentially all (100 percent) of the fission products from an airburst are very small in size and for the large yields that we have assumed they remain high in the atmosphere (stratosphere) for very long periods of time (half residence time the order of years or more) and return to the earth's surface as worldwide contamination.

Senator HICKENLOOPER. Mr. Chairman.

Representative HOLIFIELD. Senator Hickenlooper.

Senator HICKENLOOPER. I notice in the statement you say in the order of a year or more, but in your verbal statement you said years or more. There seems to be a distinction there.

Dr. SHELTON. I will leave it as it is in the text, "the order of a year or more." As we saw during the hearing last month, this is the order of magnitude and it is tied rather intimately to the latitude in which the bomb goes off. If it is high latitude, it is short. If it is equatorial, probably longer. And for the temperate latitude, I am inclined to think it is the order of a year or more.

Representative HOLIFIELD. And it does also take into consideration the factor of the half life of the different isotopes. The shorter lived isotopes would decay, maybe, in a few seconds or minutes or weeks or years, and longer-lived isotopes might last as long as many hundreds of years.

Dr. SHELTON. That is correct. I will say a few more words about the elements in worldwide and the local fallout pattern.

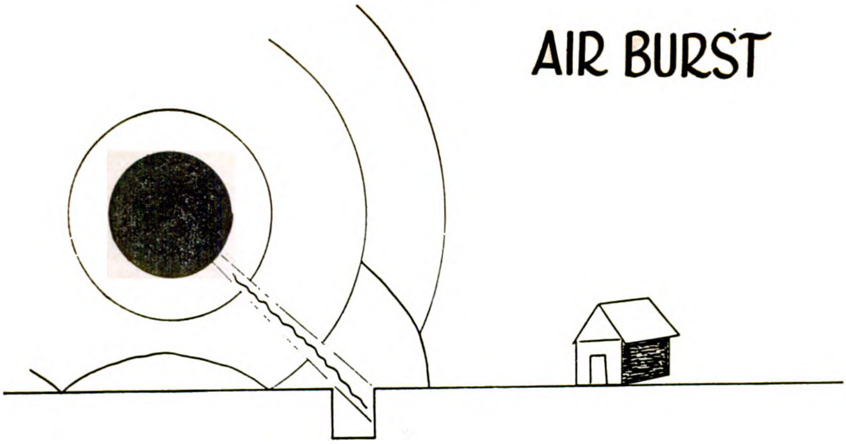
Just a few words about airbursts and surface bursts. I realize again, we have assumed surface bursts for the attack.

II. DIFFERENCES IN AIRBURSTS AND SURFACE BURSTS

A. Airburst

An airburst is one in which the fireball at no time comes in contact with the earth's surface (see fig. 2). This means essentially that the local fallout is negligible, because the radioactive fission products themselves are very light particles which are carried up in the rising cloud and remain aloft for very long periods of time, so that most of them decay to harmless inactive materials before they ever reach the earth's surface. In a large yield airburst nearly all (about 100 percent) of its fission products are deposited in the stratosphere and hence this type of burst makes the maximum contribution to worldwide fallout. In an airburst the blast wave is reflected in the earth's surface and reinforces the incident wave and results in a wider area of damage near the surface than would be the case of a surface burst of the same yield.

FIGURE 2



However, the extremely higher overpressure levels may not reach the earth's surface if the burst is sufficiently high. It also means that, in general, the thermal and prompt nuclear radiation received by ground targets will be more direct and harder to shield against.

B. Surface burst

A surface burst is one in which the fireball does intersect the ground (see fig. 3). In this case there is some direct energy loss to the surface, resulting in a small decrease in thermal, blast, and prompt nuclear radiation. However (local) fallout is maximized in a surface burst, due to the particulate matter that is sucked up into the column and cloud and which becomes radioactive. Also a crater is formed in the vicinity of the burst because of the material displaced by the extremely high pressures, thrown out by the explosion, and vaporized by the intense heat. This crater is usually characterized by an extremely radioactive area. The radiant thermal energy and the nuclear radiation effects are sometimes reduced, in the case of a surface burst, by natural shielding effects such as hills and buildings. About 20 percent of the fission products are deposited in the stratosphere to form worldwide fallout.

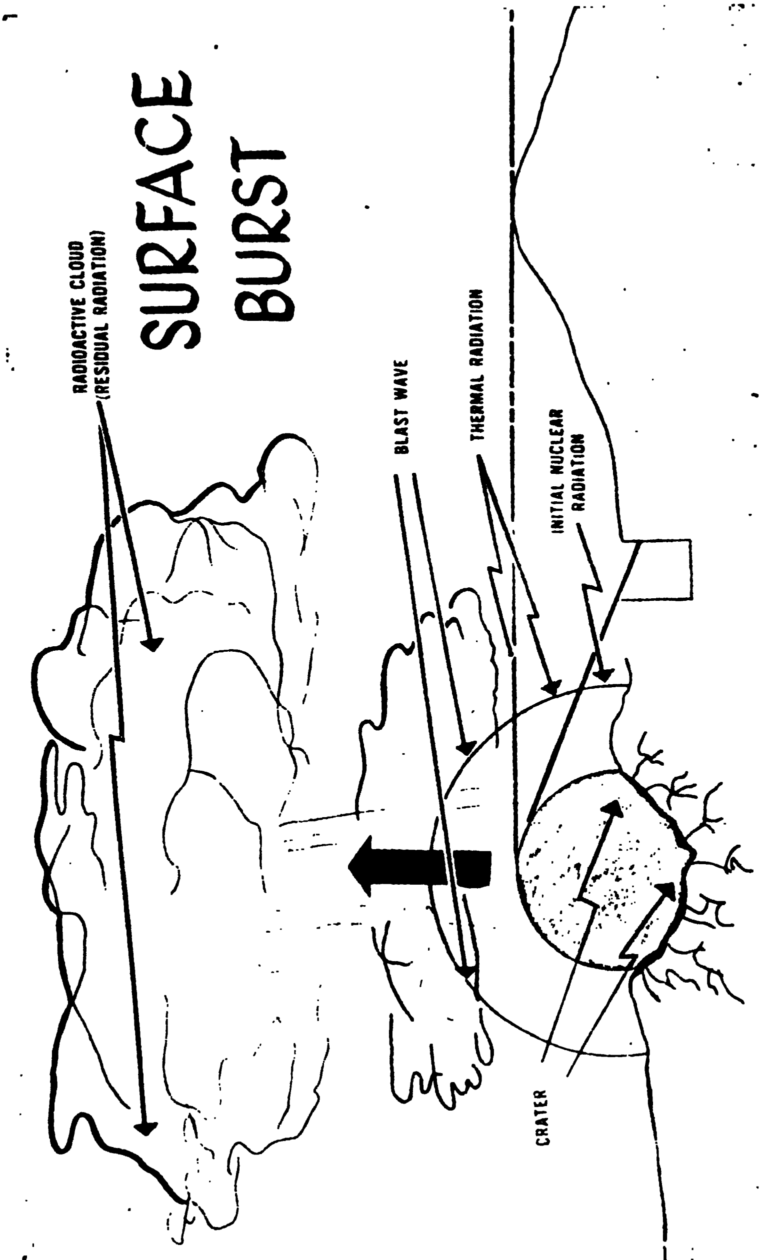
III. VARIOUS NUCLEAR WEAPONS EFFECTS ON MAN AND INANIMATE OBJECTS

Now that we have briefly reviewed the phenomena of a nuclear explosion as they are effected by the burst geometry, let us consider the effects on people and things.

Representative HOLIFIELD. Before you do that, Dr. Shelton, you mentioned a distinction between an airburst and a surface burst in the amount of residual fallout.

Dr. SHELTON. Yes, sir.

FIGURE 3


SURFACE BURST
RADIOACTIVE CLOUD (RESIDUAL RADIATION)
BLAST WAVE
THERMAL RADIATION
INITIAL NUCLEAR RADIATION
CRATER

Representative HOLIFIELD. And almost all of that of an airburst being of residual nature——

Dr. SHELTON. It will produce the same amount of fission products.

Representative HOLIFIELD. As to the total product.

Dr. SHELTON. Essentially the same.

Representative HOLIFIELD. Would you clarify that, please?

Dr. SHELTON. Let us just say that the amount of fission products produced is a function of the bomb itself and not so much a function of its surroundings. The surroundings modify or change the characteristics of the fission products as to whether they are very small and so on, but the same amount of fission products would be produced for a 1-megaton burst, whether used as a 1-megaton airburst or surface burst. This is a function of the weapon itself and it is the environment that changes the character or how the fission products will manifest themselves, whether they are carried long distances aloft or whether they happen to fall out rather close to the target.

Representative VAN ZANDT. Mr. Chairman.

Representative HOLIFIELD. Mr. Van Zandt.

Representative VAN ZANDT. Are you familiar with the surface burst that took place at Alamogordo many years ago; I think in July 1945.

Dr. SHELTON. Just barely. This is a question of a normal yield on a hundred-foot tower. It had almost no crater. There was a depression several feet deep. That gets borderline to what I call surface bursts, anyway it was close to the ground.

Representative VAN ZANDT. Are we still fencing that area and refusing to admit people?

Dr. SHELTON. I am not familiar enough with the subject to answer that directly. I would rather imagine that we are not, except to keep the curiosity down in the area. I am not an expert in that area.

Representative VAN ZANDT. Does Dr. Libby know?

Dr. LIBBY. I do not happen to know, Mr. Van Zandt. We will find out for the record for you. I do not know offhand.

Representative VAN ZANDT. Thank you.

(The material referred to follows:)

PRESENT STATE OF THE TRINITY TEST SITE

The Trinity site is now inside the White Sands Missile Range and consequently is off limits to civilians under ordinary circumstances. (The missile range is a posted military reservation.)

The radioactivity in the fused sand of the crater area has decayed to low levels, and does not constitute a significant hazard.

Although an area around ground zero about 1,400 feet across is still fenced, the fence is no longer needed for either health or security reasons.

Dr. SHELTON. Mr. Chairman, I would like to discuss the effects and to begin with the effects on inanimate objects. And of the various effects, let us start with blast.

A. EFFECTS ON INANIMATE OBJECTS

1. Blast wave

First describing blast, it is a primary damaging agent to inanimate objects. The blast damages structures in two ways; first the air at the shock front is quite dense and exerts a static overpressure in all directions which decreases gradually behind the shock front. This

overpressure produces a crushing effect on the structure as it engulfs it. Since the blast wave is also a mass of air in motion at very high velocity, it exerts a dynamic force on the structure, tending to translate it in much the same manner as a hurricane wind. Such structures as multistory brick apartment houses are quite vulnerable to the blast wave. (See fig. 4.) All such structures would be destroyed, collapsed, within a radius of 7 miles from ground zero for a 10-MT weapon; that is, one having a total energy equivalent of 10 million tons of TNT.

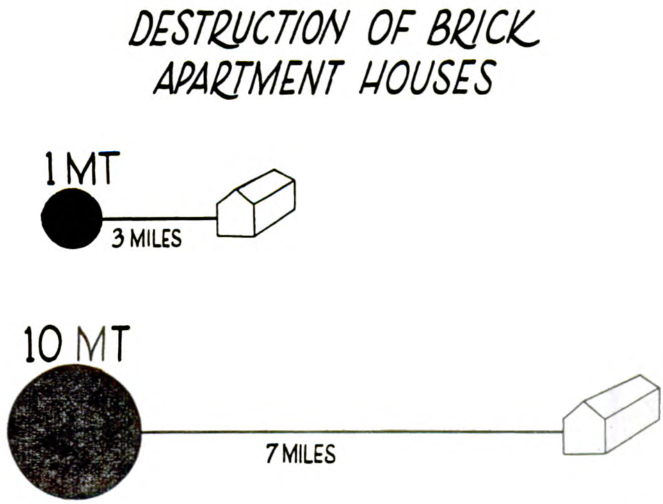
If we decrease the yield by a factor of 10, we have a 1-megaton weapon. For this yield, all such structures within a radius of over 3 miles from ground zero would be destroyed for a surface burst. Thus, a factor of 10 in yield will change the radius of blast damage by a factor of little more than 2.

Senator HICKENLOOPER. Just a moment, Mr. Chairman.

Representative HOLIFIELD. Senator Hickenlooper.

Senator HICKENLOOPER. I am having a little trouble here with the verbiage. You say if we decreased the yield by a factor of 10, we have a 1-megaton weapon. Then this sentence——

FIGURE 4



Dr. SHELTON. It refers to the previous sentence. We decrease the 10 megatons to 1 megaton.

Senator HICKENLOOPER. I understand you decrease the 10 to 1, but then this sentence.

For this yield, all such structures within a radius of over 3 miles from ground zero would be destroyed for a surface burst.

As I take it that statement says everything over 3 miles beyond the center of the surface burst would be destroyed whether it was a hundred miles away or 200 miles away.

Dr. SHELTON. I can understand the problem there.

Senator HICKENLOOPER. We are dealing with a very technical and with a very, if I may use the word, frightening subject here, and I am concerned with the literal statements that are made.

Dr. SHELTON. You are perfectly correct. Let us change the record to read in its proper context something as follows: "for this yield of 1 megaton all structures within a radius of slightly over 3 miles." It means that I rounded everything off to whole numbers of miles.

Senator HICKENLOOPER. Personally, I was quite sure that was what you meant, but I could see headlines that could be, perhaps, based exactly on the statement that was here, that everything beyond 3 miles would be destroyed, which I do not think is right.

Dr. SHELTON. I appreciate your remarks, sir, and I am sure you are correct.

Senator ANDERSON. Going back to the verbiage on the previous page, on page 3—can I go back to that just a second?

Dr. SHELTON. Yes, sir.

Senator ANDERSON. Under "Air" you say—

In a large yield airburst, nearly all of the fission products are deposited in the stratosphere and hence this type of burst makes a maximum type of contribution to worldwide fallout.

I read that to mean that airbursts make the maximum contribution to worldwide fallout. In the next paragraph on the "Surface" you say:

However, fallout is maximized in a surface burst. You cannot maximize both the air and the surface.

Which is which?

Dr. SHELTON. Let us return to the airbursts. First, it is a large yield airburst and it has to be large yield, Senator Anderson, you see, to deposit it in the stratosphere.

For airbursts and the weapon yields assumed in our particular case, 1 to 10 megatons are sufficiently large to deposit, if airbursts, essentially all of their fission products in the stratosphere and hence this type of burst puts all of its fission products in the stratosphere and makes a maximum type of contribution to worldwide fallout.

In the case of the surface burst and with the yields we are considering, it deposits only 20 percent of its fission products in the stratosphere and the other 80 percent as local fallout. In the case of the surface burst, it makes the local fallout situation a maximum, local high intense fallout for a surface burst.

Senator ANDERSON. Is it any different from what we might call "dirt"? In the two types of explosions, is one dirtier than the other?

Dr. SHELTON. No, sir. I am using precisely the same weapons. To the person or people in the vicinity of the detonation, of course, the airbursts have essentially no local fallout. There is no fallout characterizing it except as worldwide over a long period of time.

Senator ANDERSON. All you are trying to say in these two sentences is, if you have an airburst the fission products are maximized way up in the stratosephere, and, if you have a surface burst they are maximized down there locally to the people around and has far more radioactive products in it because of the things sucked up into the fireball.

Dr. SHELTON. Yes; in my reading text, I have corrected the surface burst, third sentence—

However, local fallout is maximized in a surface burst.

Thank you, sir.

Senator ANDERSON. That is an important word, is it not?

Dr. SHELTON. Yes, sir.

Representative HOLIFIELD. For further clarification, let us understand what we mean by airburst in terms of altitude. Do you mean an airburst where the fireball does not touch the ground, where it is a mile high, 2 miles, or just what are we talking about now in terms of airbursts?

Dr. SHELTON. An airburst of 1-metagon yield should be in excess of about 2,000 feet above the ground.

Senator ANDERSON. Do I understand that the detonation of an airburst depends upon the size of the weapon?

Dr. SHELTON. Yes, it does. But how high it would have to be——

Senator ANDERSON. For a long time was not 1,500 feet regarded as the measure for an airburst? You said 2,000. You are not far apart. Would your definition, generally, be that an airburst is anything over 1,500 or 2,000 feet?

Dr. SHELTON. I make my definition a little more precise than that. The fireball, that large radiant volume, is about 180 or 200 feet in radius for a 1-kiloton weapon.

Representative HOLIFIELD. One KT being 1,000 tons.

Dr. SHELTON. One thousand tons. It is about 180 or 200 feet in radius. For a 1-KT weapon, if I employed it like 200 or so feet above the ground, it would be essentially an airburst. To go to a megaton, there is a way to scale the size of the fireball, and it would be 10 times larger. It would only be 10 times larger radius for 1 megaton than the 1 KT. I say 180 or 200 feet times 10 is about 2,000 feet for a megaton burst. All I am trying to do is to keep that extremely hot fireball region from being in contact with dirt.

Representative HOLIFIELD. So the center of the fireball would be different degrees of altitude for the different size bombs in order to keep the outside edge of the fireball from touching the ground.

Dr. SHELTON. That is correct, sir.

Representative HOLIFIELD. The question might well come at this time, why should there be airbursts or why should there be ground bursts? I think as long as the ground bursts were used in the assumption, it should be stated that the assumption was to use the bombs in the same way they were used in the Hiroshima and Nagasaki explosions, and, from the standpoint of military damage, the surface burst would be considered by an enemy to be more effective than a bomb burst higher in the air. If the enemy wished to preserve the structures on the ground and radiate the population he might, from a tactical standpoint, burst the weapon higher in the air. Is that substantially correct?

Dr. SHELTON. I would like to correct only one portion of what you said, and that is, Hiroshima and Nagasaki were nominal yield weapons of about 20 kilotons, detonated high in the air. They were detonated at altitudes of 1,800 or 2,000 feet. They were high airbursts and produced no local fallout. These weapons assumed in the attack here were surface bursts, and do have local fallout and hence are not, I would say, like the Hiroshima-Nagasaki situations. The reasons for surface bursts and airbursts are essentially as you explained.

Representative HOSMER. I would like to get back to the ground burst situation where you contaminate the real estate and pull it up and put it in the stratosphere. Doesn't that add something over and above what an airburst adds to the fallout effect of the detonation?

Dr. SHELTON. I am not sure I understood the question, Mr. Hosmer. Will you repeat it, please?

Representative HOSMER. Yes; where you have a surface burst, you have a direct effect on the property which is in terms of radiation, the creation of fission products, which are in turn sucked up, much of which goes into local fallout, but isn't there also a contribution to the long-range fallout?

Dr. SHELTON. Yes; there is a contribution to long-range fallout.

Representative HOSMER. That is in addition to direct product of the detonation.

Dr. SHELTON. That is in addition to the direct products of detonation.

Senator ANDERSON. Do you agree with that?

Dr. SHELTON. Congressman Hosmer says in a surface burst there are some other products produced other than those directly from the bomb. What he is saying is that there is a small contribution due to the induced activity in the soil perhaps. It is radiation due to neutrons on the soil and does have the possibility of making perhaps a very small additional radioactive contribution other than the fission material from the bomb, such as activated trace elements in the soil.

Representative HOLIFIELD. But this is an important factor, for the tower burst that scooped out the island about a mile across in the South Pacific, we have been told, took several hundred million tons of coral up into the atmosphere, the troposphere, and stratosphere. This material did become induced with radioactivity. Therefore, it is a factor of transportation in the atmosphere where an effect like that of irradiated dust particles occurs which did not exist in the components of the bomb. There is a very definite factor of increased transportation of particles which are radioactive. Is that correct?

Dr. SHELTON. Yes; the coral particles are radioactive in the case of the surface burst in your example. They are radioactive primarily and principally due to the fission products of the bomb adhering or becoming imbedded in them. There is, as you say, the chance of some trace elements in the native material also becoming activated. But this contribution is usually very small compared to the fission product activity itself.

Representative VAN ZANDT. Doctor, where you use a 10-megaton and a 1-megaton weapon, is it your assumption that everything within the radius of 10 or 3 miles would be destroyed; I take it you are assuming the terrain is flat.

Dr. SHELTON. The situation, Mr. Van Zandt, in the case of blast, is that there is very little, if any, blast reduction due to hills. There is a slight increase of blast on the forward slope of a hill and a slight reduction of blast on the back slope of a hill, that is true. That is usually not a very important factor in determining the distance at which substantial damage would occur. In other words, the reduction is usually small.

Representative VAN ZANDT. Isn't it true that Nagasaki is in a river valley?

Dr. SHELTON. Yes. It is in rather hilly terrain.

Representative VAN ZANDT. And the blast effects were only felt at a certain height up such side of the slope, and beyond that point the destruction tapered off.

Dr. SHELTON. I believe the destruction existed. It was not severe enough when it got on the back side of the slope. It would probably not have destroyed a building there even if it had been on flat terrain at that distance.

Representative VAN ZANDT. Do I understand, Doctor, if we had a surface burst in a river valley the blast effects would be felt on the other side of the hills lining the valley?

Dr. SHELTON. They sure would, depending only on the distance.

Representative VAN ZANDT. But not reduced?

Dr. SHELTON. Not reduced substantially enough to worry about. We have done this sort of thing to the best of our ability in the Nevada area. We do know quite a bit about the small blast enhancement on the front side and the small degree of blast reduction on the back side of a hill.

Representative VAN ZANDT. Does this apply to thermal radiation?

Dr. SHELTON. When I get to thermal, the shielding there can be very important and direct. I will say a few words about that.

To repeat again, a 1-megaton burst would destroy brick apartment houses to about 3 miles, a 10-megaton to about 7 miles. So you see that for a 10 times larger weapon, the distances change by a factor of about 2 or slightly more. For any other yield in between 1 and 10 megatons, it would be proportionate, someplace within the factor of 2. For instance, about 8 megatons would have been exactly the factor of 2. Three megatons would be just slightly more than 4 miles. It would not be 5 miles, for instance, within which brick apartment houses would be destroyed.

Not everybody lives in brick apartment houses. I would like to say a few words that are not in my text about frame houses. A well-constructed frame house completely collapses within 9 miles of a 10-megaton burst and 4 miles of a 1-megaton burst—9 miles from 10, 4 miles from 1. In discussing the collapse of buildings and one's home, while one is encouraged to build a shelter in his basement, very few visualize their homes collapsing, bricks, furniture, and all, down into the basement. If you live in a brick house and it is within 7 miles of the general downtown area, it will probably collapse from a 10-megaton burst. If you live in a wood frame house about 9 miles from the general downtown area, it will collapse from a 10-megaton burst.

You can visualize this by how far you drive to work. If it is within those distances or less than 9 or 7 miles, your home will fall down, and if you are lucky enough to have a basement, it will probably fall down into the basement.

What are you going to do in your basement when your house falls down into it?

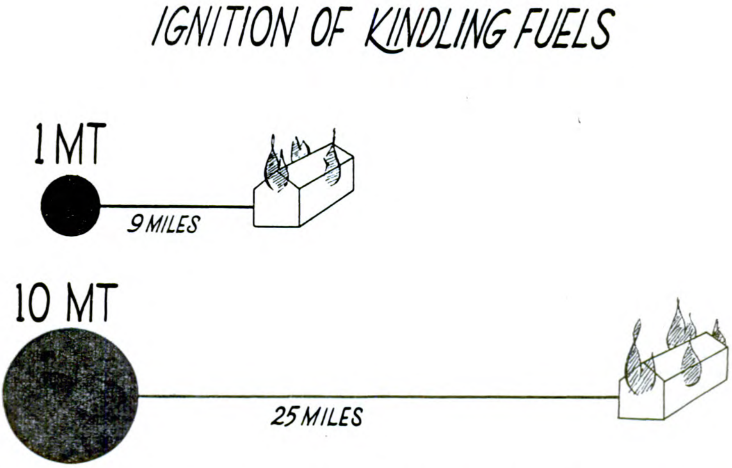
2. THERMAL RADIATION

I would like to move to the subject of thermal radiation. It is probably second in importance in producing damage to inanimate objects.

When combustible materials receive sufficient radiant energy within a short period of time, they will ignite. Thus in the presence of kindling fuels in built-up areas near a nuclear detonation this would very probably result in widespread fires. For example, fires could be started by the ignition of light kindling material anywhere within about 9 miles of a 1-megaton weapon, and for 10 times that yield or 10 megatons it would result in the ignition of light combustible materials anywhere within 25 miles of the burst (see fig. 5). That is a distance, as you see, about three times larger than for the 1-megaton burst. There is a factor of 3 in radius in going from 1 megaton to 10 megatons in which we would expect the ignition of fine kindling material.

Representative HOLIFIELD. When you are talking about fine kindling material and light combustible material, are you talking about the type of siding that is used on frame houses and that kind of material?

FIGURE 5



Dr. SHELTON. In the case of the numbers given here I was talking about something that was perhaps a little more combustible than that. Like the curtains of a house, the paper or litter that is apt to be found in yards. There are something like three ignition points per acre in good residential areas. It goes up to about 20 ignition points per acre in slum areas.

The materials I am talking about depend generally on the tidiness of the area. I am talking about the materials that are generally combustible—paper, litter, boxes, and in the case of good residential areas, I am talking about curtains and other quite flammable materials.

The numbers referred to here are fairly light combustible materials. To burn a house down or to ignite a house, a good painted house, would certainly not occur at these distances.

Representative HOLIFIELD. Could you give us an estimate of that so we can have the record complete?

Dr. SHELTON. Let me provide that and not take the time right now.

Representative HOLIFIELD. All right.

(The information referred to follows:)

THERMAL IGNITION OF FRAMEHOUSES

There is some uncertainty as to whether or not persistent ignition can occur to well-painted good wood, such as the type of siding that is used on framehouses, under the conditions of a nuclear explosion. The following quotations are taken from "The Effects of Nuclear Weapons," and the referenced paragraph numbers are given:

7.62 "Wood is charred by exposure to thermal radiation, the depth of the char being closely proportional to the energy received. For sufficiently large amounts of energy, wood in some massive forms may exhibit transient flaming, but persistent ignition is improbable under the conditions of a nuclear explosion. However, the transitory flame may ignite adjacent combustible material which is not directly exposed to the radiation. * * *"

7.93 "From the evidence of charred wood found at both Hiroshima and Nagasaki, it was originally concluded that such wood had actually been ignited by thermal radiation and that the flames were subsequently extinguished by the blast. But it now seems more probable that, apart from some exceptional instances, such as that just described, there was no actual ignition of the wood. The absorption of the thermal radiation caused charring in sound wood but the temperatures were generally not high enough for ignition to occur. Rotted and checked wood and excelsior, however, have been known to burn completely, and the flame is not greatly affected by the blast wave."

7.82 "The fact that accumulations of ignitable trash close to a wooden structure represent a real fire hazard was demonstrated at the nuclear tests carried out in Nevada in 1953. In these tests, three miniature wooden houses, each having a yard enclosed with a wooden fence, were exposed to 12 calories per square centimeter of thermal radiation. One house, at the left, had weathered siding showing considerable decay, but the yard was free from trash. The next house also had a clean yard; and, further, the exterior siding was well maintained and painted. In the third house, at the right, the siding, which was poorly maintained, was weathered, and the yard was littered with trash."

7.38 "The state of the three houses after the explosion was as follows: The third house, at the right, soon burst into flame and was burned to the ground. The first house, on the left, did ignite but it did not burst into flame for 15 minutes. The well-maintained house in the center with the clean yard suffered scorching only. * * *"

Thermal effects comparable to those existing at these three houses would occur at 13 miles from a 10-megaton burst and at 6 miles from a 1-megaton burst.

Dr. SHELTON. Thus not only may your house be blown down, but it may be on fire due to the ignition of curtains or inflammable materials outside the house. There is a chance of a very large general fire throughout the area, a conflagration or fire storm. A fire storm existed at Hiroshima and lasted about 6 hours.

Representative HOLIFIELD. Will you explain for the record what a fire storm is?

Dr. SHELTON. In the case of Hiroshima, the fire storm was a general burning in the area of the target with air sweeping in, feeding the fire from all sides, and the heat rising up, a great smoke pall moving upward and out of the general area, so that there was a mass circulation of air. In other words, new fresh air was coming in to feed the fire. It burned for about 6 hours. At the edge of the fire storm there were winds like 30 and 40 miles an hour, and those generally subsided and became rather small and variable at the end of 6 hours.

The reason I mention the fire situation is that a fire that burns for times like 6 hours, raging in an area, even shelters there would have to

have perhaps their own air supply since ventilation would suck in very hot air. It could be of the order of thousand degree temperature air and scorching. The problem of a general fire as characterized by a fire storm in a large metropolitan area has just probably never been witnessed. To start these many ignition points all at once is certainly beyond any incendiary attack that occurred in World War II, I would say. That is thermal and its effect on inanimate objects.

Representative BATES. What do you mean by calorie level? Is that thermal level or are they interchangeable?

Dr. SHELTON. Yes. I mentioned in the case of the larger weapon that I needed a little more thermal, a little higher calorie level to start the fire than I did for a 1 megaton. I need more calories than from the 1 megaton burst simply because the 10 megaton bomb delivers its heat a little slower and to get the material up to a kindling point, I needed a little more heat. Calorie is a definition or a yardstick for heat.

3. Initial nuclear radiation

Initial nuclear radiation, that is emitted directly from an exploding bomb for a short time thereafter, has very little effect on inanimate objects. The same is generally true of residual fallout except that fallout can deny the use of the inaminate object to man until it can be decontaminated.

4. Crater

The crater is another effect, a region of extreme severity. There is a crater produced in the case of surface burst and even such very hard targets as aircraft runways, underground installations and even shelters and underground subways which are quite invulnerable to the other effects, but can be destroyed in the crater. A 1 megaton surface burst in dry soil—and the only reason I say dry soil is that the size of the crater does depend a little on the soil conditions—a 1-megaton surface burst in dry soil produces a crater about 1,300 feet in diameter and about 140 feet deep. (See fig. 6.) The diameter is small compared to the other dimensions we have been discussing, and a 10 megaton surface burst in dry soil produces a crater twice as large, actually 2,500 feet, and about twice as deep, or 240 feet deep.

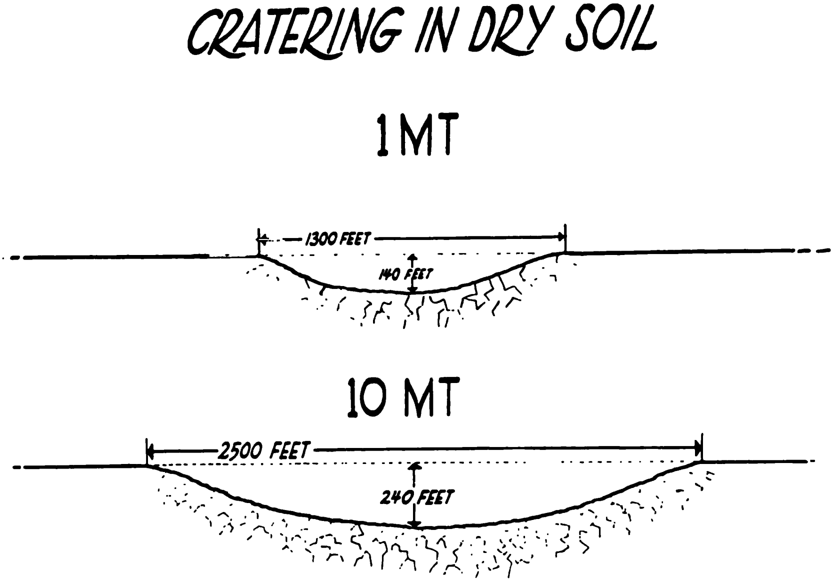
The damage would not be confined just to the extent of this region. It would extend beyond that, because there is an enormous shattering and rupture of the soil within the distance of another crater radius. I would not expect any structure or its occupant to survive in the region of the crater, and even to a distance of again another crater radius. That is an extremely shocked, ruptured area.

Representative HOLIFIELD. In order that I may clearly understand what you have said, if the crater is 1,300 feet in diameter, how wide would the damage area be?

Dr. SHELTON. An area 2,600 feet across would be an extremely severely affected area. Enormously large accelerations, crushing of even very large structures.

Representative BATES. Is it 2,600 feet or is it twice that?

FIGURE 6



Dr. SHELTON. We have an area within 1,300 feet radius of a 1 megaton burst. How big an area would be affected was the question, and that would be 2,600 feet diameter or within 1,300 feet of the ground zero. That would be an extremely severely affected area. There is always a chance that this crater breaches the subways. The people very often in very large metropolitan areas discuss using their subways. There are no subways that I know of in the New York City area as deep as 240 feet. If the crater breaches the subway, it will send a blast away down it and pretty well clean it out for distances like several miles, I would imagine.

B. EFFECTS ON MAN

I would like now to discuss the effects on man. This will begin with the initial radiation.

1. Initial radiation

Whatever the form of nuclear radiation, the end result in cells of the body is qualitatively the same. Despite the fact that different radiations cause ionization by different mechanisms and to varying degrees, the primary biological response to all ionizing radiation is one of cellular damage or destruction. The first question that one naturally asks is, how much radiation is necessary to be harmful.

Since we are all exposed to a natural background radiation of about 0.15 roentgen per year, it is obvious that a small amount will produce only small and hardly noticeable effects. However, as the amount of radiation increases for the whole body, the danger becomes more and more acute. What we are usually concerned with is the effectiveness on an individual, that is, one who as a result of the radiation dose received is unable to perform those tasks that would contribute to his survival.

The time required to render a person ineffective becomes less as the total dose increases. We measure radiation in rem. We call it roentgen equivalent mammal. A rem is defined as the amount of radiation of any type required to produce a biological effect, that is the destruction of cell materials, equivalent to that of 1 roentgen of X-ray.

As an example, 200 rem will cause vomiting and nausea in 50 percent of the population by the end of the first day, but none or very few would be expected to die. A dose of 450 rem would cause vomiting and nausea in all of a group by the end of the first day, and about half of the people exposed would be expected to eventually die. When exposed to 600 rem the entire group would become sick within 4 hours and a very large percentage, perhaps all of them, would eventually die. A dose of 1,000 rem, which is something like the dose to last person at Los Alamos who died from an accident, would cause them to be incapacited in an hour or two and all eventually die.

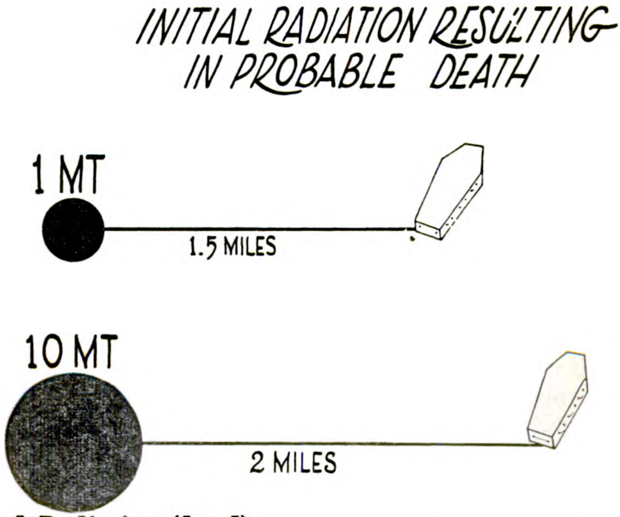
A 1-megaton weapon would deliver at least 700 rem within a range of 1.5 miles. (See fig. 7.) For a 10-megaton weapon, the lethal range would be a little more than 2 miles.

Representative HOLIFIELD. Is that from point zero? Is that a radius figure?

Dr. SHELTON. These are all radii, yes, sir. From this it is fairly apparent that a very large increase in yield changes only slightly the lethal radius of the initial radiation. In other words, moving up a factor of 10 in yield changes the radius from 1½ to 2 miles.

This is a prompt dose of radiation that certainly means death to the unshielded or unsheltered in this region. It is, however, a region that is lethal for nearly all of the other effects.

FIGURE 7



2. Residual Radiation (*local*)

Moving from the prompt radiation to the residual radiation, and in this case the local fallout, again we recall that this is a phenomenon caused by the dirt from a surface burst being taken up into the fire-

ball and cloud where some of it is vaporized together with the fission products of the bomb. As the cloud cools, the debris condenses and the radioactive particles are trapped on or in a very large number of soil particles of various sizes. It is to be noted in the case of a thermonuclear weapon that only that portion of the yield due to fission contributes to this falout. For a 10-megaton surface burst, I would expect the top of the cloud to be somewhere near 90,000 feet, and the bottom of the cloud at about 60,000 feet. The heaviest particules fall to earth rather rapidly, and the lighter ones are carried into the upper atmosphere with the cloud, and then carried downwind from ground zero by the winds aloft for distances like several hundred miles.

The result is a fallout patern of quite irregular shape, usually, and it depends very intimately on the wind pattern. A 600-r-per-hour dose rate—that is the rate at which radiation is being emitted from the ground—contour for a 1 megaton surface burst, with our assumed 50 percent fiission, would enclose an area about 80 square miles; for a 10-megaton weapon with 50 percent of its yield due to fission, the 600-r-per-hour contour would enclose about 1,300 square miles.

We have said that the H plus one—this is the 1 hour dose rate of 600-r-per-hour—does not mean that a person in the open would be receiving radiation at that rate. The fallout may not have even arrived at his position, for instance, at 1 hour. It would be perhaps more meaningful to note just how much total radiation a person would receive for a given length of time within these areas.

For the 10 megaton 50 percent fission yield weapon in the first 48 hours, the accumulated dose would probably be in excess of 780 roentgens, which is fatal to all the people exposed in the open without shielding during that period. You will recall that was the area that was about 1,300 square miles, and I will say a few more words about these areas in a few moments.

I am now going on to say a few words about strontium 90 in the local fallout area. In an area covered with an intensity of 1,000 r per hour at 1 hour, there is strontium 90 deposited in the local fallout, if it is deposited in an unfractionated way. By that I mean it has not been separated preferentially in some way. It is coming down in exactly the proportion it was made. There would be 100 curies per square miles of strontium 90.

As a comparison, as of January 1958, the average soil deposition level in the northern temperate latitudes was 25 millicuries per square mile, or something like 4,000 times less than what I am discussing. After the war, one would not grow certain type crops on such soils, and extensive deep plowing or other methods would be required to make the soil usable for edible crops. I believe Dr. Machta will have more to say about strontium 90 in the fallout area, and I will not take any more time.

Representative HOSMER. Before you proceed, I would like to pin down the reference of your 10-megaton weapon with a 600-roentgen-per-hour contour at 1,300 square miles. At what time is that? At burst and 1 hour after, or what?

Dr. SHELTON. That is one of the confusing things about fallout and why it is usually sometimes a little hard to discuss. Let us discuss the 600-r-per-hour contour which would enclose something like 1,300 square miles. In other words, I have drawn here a long cigar shaped

thing that contains fallout along its edge of the same intensity. There is the same amount of fallout there at some late time. As the close part of the edge it is down very early, like in a half hour. At the far end of this cigar, it may not be down for 3 or 4 hours. We normalize that whole contour, the amount of fallout that eventually got down to a radiation level, and by tradtion we extrapolate it back to 1 hour. So this means that at 10 hours after the burst, it is all down in that area.

Let me take 7 hours. Let us say it is all down in 7 hours. Then the radiation pattern is the same at 7 hours all around that periphery.

Representative HOSMER. Is that when your 600-roentgen figure is taken or when?

Dr. SHELTON. If it was down at 1 hour it would be 600 roentgens. If you are talking about 7 hours, it turns out to be a tenth of that. It is probablly 60 roentgens per hour.

Representative HOLIFIELD. Isn't it true that near ground zero in a megaton bomb your initial irradiation is around 3,000 roentgens an hour? It decreases by a factor of 10, in other words, to 300-roentgens-per-hour rate at 7 hours from the time of explosion.

Dr. SHELTON. That is correct.

Representative HOLIFIELD. In another 7 hours it would be down to 30?

Dr. SHELTON. That is right.

Representative HOLIFIELD. In another 7, it would go then to 3?

Dr. SHELTON. That is about right.

Representative HOLIFIELD. In another 7 it would go to 0.3?

Dr. SHELTON. If these are a factor of 7 in time.

Representative HOLIFIELD. Yes. In other words, you have 3,000 roentgens per hour at time of burst which would be reduced in 28 hours to 0.3 roentgen rate. That is four 7-hour periods.

Dr. SHELTON. That is what is not quite right. Let us say there are 3,000 roentgens per hour at 1 hour. In 7 hours it is certainly 300. It takes another factor of about 7, which is 49 hours, or 2 days, to become 30. It takes another factor of 7, 2 days times 7, or 14 days, or 2 weeks to be reduced by another factor of 10.

Representative HOLIFIELD. I see. Then your factor of 7 hours does not come through. After the initial 7 hours, you change to another formula?

Dr. SHELTON. It takes a sevenfold increase in time to bring it down a factor of 10. The first sevenfold is the first 7 hours. The next factor of 7 is 2 days. Then the next 7 is 2 weeks. Then it takes 14 weeks to decrease it another factor of 10.

Representative HOLIFIELD. I think this is very important. Are we to consider the hourly rate as the total amount of radiation that a man gets within 1 hour?

Dr. SHELTON. Yes.

Representative HOLIFIELD. In other words, he will get 3,000 roentgens within the first hour: the second hour would be a factor less than that. I don't know what that factor would be, but let us say it was 3,000 minus; he would get that much more in the second hour. In the third hour he would get whatever the rate is there.

Dr. SHELTON. It is close to that. It is decreasing quite fast in the early hours so that if it is only 600 roentgens per hour at 1 hour, then

in an hour and a half it is not 600 roentgens per hour any more; it is quite a bit less than that. That was the purpose of the little example. This business of 600 roentgens per hour at 1 hour may have very little meaning.

Representative HOSMER. May I ask you this in relation to the "Yes" answers you gave to the chairman's questions? Let us get this 600 roentgens per hour in your testimony related to some order of magnitude of time following the blast. Can you do that?

Dr. SHELTON. Yes, sir. We will read the text for the 10-megaton 50-percent-yield weapon. If you were standing out in the open, unshielded, on the 600-roentgens-per-hour at 1-hour contour for 48 hours—that is, for the first 2 days—you accumulate 780 roentgens, which is fatal to all of the people exposed in the open without shelter.

Representative HOSMER. Dr. Shelton, I would again like to ask my question, because you didn't answer it.

Dr. SHELTON. I am sorry.

Representative HOSMER. I would like to know how long after the bomb is this 600-roentgens-per-hour calculation that you have in your testimony. How long after the explosion? Just an order of magnitude.

Dr. SHELTON. The 600-roentgens-per-hour contour is deposited as a function of time. The answer is that there is no simple answer. There is a 600-roentgens-per-hour contour that encloses the burst point in the upwind direction. At that point I would expect the fallout to be down in like a half hour. There is a 600-roentgens-per-hour contour, which is a yardstick of how much radioactivity will eventually fall down at another point—100 miles downwind, for instance—but it may not exist at 1 hour. It is just a measure of the amount of fallout that will come down. If it had been down at 1 hour, that would have been its radiation rate.

Representative HOSMER. Then your 1,300-square-mile radius, right on the periphery of where you have drawn your line, how long after the bomb has detonated is that line reached?

Dr. SHELTON. For a 10-megaton weapon, I would imagine it would take up to 8 hours in the downwind direction.

Representative HOLIFIELD. Is that computed on a 15-mile-an-hour wind?

Dr. SHELTON. It is like that; yes. I think that is for 15 knots. You will find the winds over the United States are more like 40 miles average from 60,000 feet down to ground.

Representative HOSMER. If that is 600 in 8 hours, what, roughly, would it be at 16 hours? Just an order of magnitude?

Dr. SHELTON. It would have been 600 if it was down in 1 hour. In 7 hours it would have been 60. So if it is all down in 7 hours, that contour that I am talking about actually reads 60 roentgens per hour on a radiation meter. In 2 days it will be 6 roentgens per hour.

Chairman ANDERSON. Doctor, do you think it is very easy for the average person to understand that?

Dr. SHELTON. No. That is why I said if you are standing on this contour out in the open for 48 hours, you are going to be dead on the radiation contour I am talking about.

Chairman ANDERSON. If I am 7 miles away from a 10-megaton bomb, do your figures show me how much radiation I am going to get the first hour? Will I get enough in the first hour to kill me?

Dr. SHELTON. No; they do not.

Chairman ANDERSON. Isn't that what the average person wants to know?

Dr. SHELTON. Yes.

Chairman ANDERSON. Doesn't he want to know if this poses any problem? He doesn't understand the term "600-roentgen contour."

Dr. SHELTON. That is right.

Chairman ANDERSON. Can you give us any figures on what happens to the individual who is standing so many miles away at the time the bomb detonates? That is why I am attracted to Congressman Hosmer's question; he wanted to know how long this took place after the bomb detonated. We have been out to explosions. We know we don't hear it until a long time after we have seen it. What happens to the effects? How long before we get those?

Dr. SHELTON. Whether you are affected at all or not, Senator Anderson, depends on which way the wind is blowing that day.

Senator ANDERSON. I can't tell that when the bombs come down, probably.

Dr. SHELTON. That is right: neither will the civil defense. It depends very intimately and crucially on the average winds all the way to 60,000 feet at the time the bomb goes off and as they change for the next several hours after it has gone off. There are prevailing winds for a given season, and one knows generally if a bomb goes off in Washington which way it is going to go. It is going to go either east or northeast. Most of our material will probably go to Baltimore. That will be the bad direction, generally.

Chairman ANDERSON. Let us take this example: The bomb goes off in the heart of Washington, and we are 10 miles northeast of Washington, that is the direction of the prevailing wind, it is a 10-megaton bomb, and I am 8 miles away. Will the blast hurt me, and if so, when will I feel it, how much will I feel it, and what will it do to me? Can you give me a litle example of what the radiation burden will be?

Dr. SHELTON. First, the blast will not be particularly severe at 10 miles. The houses will start to fall down. There will start to be flying debris. Very often one is interested in knocking down a heavy steel frame structure, for instance, and that takes a lot more pressure than wood frame houses. That will appear in the first minute.

Chairman ANDERSON. I am not too worried about that heavy steel structure. I am worried about my skin. Tell me what is going to happen to me.

Dr. SHELTON. Let us take 10 miles in that direction for a 10-megaton burst in the center of Washington. All the brick apartment houses would have fallen down within 7 miles. There will be some falling and some standing at 10 miles. If you have a wooden frame house of two stories, essentially all of those will have collapsed out to 9 miles and there will be a few weaker built ones that will be falling down at 10 miles. These will have fallen down within the first minute. If there are any fires, they would have started before the blast and gotten there. The fallout at 10 miles in the down wind

direction should start about a half hour after the burst. In other words, you have about a half hour, but I don't know what you are going to do with it. You have a half hour if you want to use it before the fallout starts.

Chairman ANDERSON. I am going to get under a shower. Somebody else can do what he wants.

Dr. SHELTON. All right. The fallout will start and it won't be very intense at a half hour, and it will build up to a peak and it will be about 3,000 roentgens per hour or more at the end of the hour, if you are about 10 miles downwind. It is going to peak and be about 3,000 roentgens per hour outside on the level ground. You could not stand more than about 15 minutes of that radiation until you will probably be incapacitated, deathly sick, and terminate in death.

Chairman ANDERSON. Thank you.

3. Worldwide fallout

Dr. SHELTON. Moving on from the local fallout it is certainly pertinent to discuss the worldwide fallout in this particular situation. I would like to say a few words about the worldwide fallout. If you remember, the large particles of radioactive debris were deposited locally, and the small minute particles from the explosion that enter the stratosphere spread more or less uniformly around the earth at a given latitude and fall to earth very slowly. As I said before, about 50 percent per year will come down to the ground. Here are those numbers that we have been discussing and let me say them once again. Here we have material away up in the stratosphere. What is going to happen to it? In 7 hours its intensity is down to one-tenth of the activity that we had at 1 hour. After 2 days it is down by a factor of a hundred. Two weeks it is down by a thousand. Three months it is down by 1 over 10,000. From this it is pretty apparent that the worldwide fallout that is coming down at a rate of about one-half per year, only contains those elements that are long lived like strontium 90, cesium 137, and carbon 14. They are the only ones that are left with any appreciable activity. To say what is happening in worldwide fallout for our hypothetical war situation, let me revert back to what we now know.

We expect 5 to 10 micromicrocuries of strontium 90 per gram of calcium to be the ultimate average value in the bone of man for the north temperate latitudes as a result of testing 90 megatons of fission yield. We know the effects for 90 megatons. Let us say what we are going to get for a thousand megatons. You get about 10 times as much. So you get 50 to 100 micromicrocuries per gram of bone calcium. I think in our war assumptions we have 2,000 megatons of fission products. So one would expect to get something like 200 micromicrocuries, which is a little larger than the maximum permissible concentration standard for the population as a whole, but which is a number, I think, that we recognize to be rather conservative. Similarly, let us talk about the genetic dose for a moment.

In the Northern Hemisphere the genetic dose from past testing has been about 0.05 rem over a 30-year genetic time period. So in the war we would expect about 0.5 rem per thousand megatons of fission yield in the weapons. We have 2,000 in our assumed case. So we would expect about one rem genetic dose. This is less than the

natural background genetic dose of 3 rem per 30 years. One must consider that even for a very large-scale war, the worldwide hazard to the countries not attacked would not be very important in terms of their survival. For those familiar with the novel "On the Beach"——

Representative HOLIFIELD. Dr. Shelton, if I may interupt you, you are talking there about it would not be important for their immediate survival?

Dr. SHELTON. Yes.

Representative HOLIFIELD. It might be important genetically over the generations, but it is not important from the standpoint of an immediate casualty.

Dr. SHELTON. That is right. I did say in terms of their survival. They can worry about the genetics. It is about the same order of magnitude as the background. There is a value of strontium 90 that is like the maximum permissible concentration, or slightly higher. In terms of their survival, they should get along quite well, I should say.

Representative HOSMER. At that point may I clarify this? Taking Senator Anderson's hypothetical situation of being 9 miles from this bomb, that is one thing.

Dr. SHELTON. Yes, sir.

Representative HOSMER. Those who are outside of this location of immediate effect, not necessarily on another continent, but outside of the location of immediate effect, they are running a very considerably lesser risk.

Dr. SHELTON. I am not going to stretch it quite that far, Mr. Hosmer. I am talking about the worldwide fallout that comes around in a slow period of time, that is, dripping out fairly uniformly.

Representative HOSMER. You are talking about residual fallout; is that right?

Dr. SHELTON. I am talking about that which is worldwide. However, in the United States, as a result of this attack, there is a lot of stringout of the local fallout pattern to very large distances. And as you say, at large distances they are running a considerably lesser risk. I am talking about those countries perhaps a thousand miles away which are not directly in the local fallout stringout pattern.

Representative HOSMER. Let us see if we can do it this way. Those that are not in this stringout area that you are talking about are not at all in the same category of risks as those who are.

Dr. SHELTON. That is right. They are affected only by worldwide fallout.

Representative HOSMER. Those who are within the stringout pattern, depending where they are in that pattern, determines the risk they are taking.

Dr. SHELTON. That is correct. And their risk is much less than those in the close-in fallout such as Senator Anderson's example.

Chairman ANDERSON. Is this last sentence a little confusing to people who are trying to understand the European attitude toward testing and so forth?

One must consider that even for a very large scale war, the worldwide hazard to the countries not attacked would not be very important in terms of their survival.

Do you think people believe that?

Dr. SHELTON. It depends on how close he is to the countries attacked, I agree. If he gets one just over the border——

Chairman ANDERSON. The Russians have some sensitive areas that are not too far inside of their area of domination and if I read the reports right, there has been some discussion with the French about nuclear installations, and we probably have some somewhere in Europe. Those will be fired in one direction and the Russians will be firing in another, and do I understand that the people in between will not be worried in this large-scale war that there will be any fallout on them? Can we go to them and say, "You people in France don't need to worry. The British will be firing at the Russians and vice versa, and there will be fallout between both, but it won't hurt you any." Is that what you are saying here?

Dr. SHELTON. No, sir. However, the remarks of the paragraph are related to the worldwide fallout pattern, and not to the local stringout pattern.

Chairman ANDERSON. This is home to them.

Dr. SHELTON. They are concerned about the local fallout situation.

Chairman ANDERSON. That is right. Is there any difference between the two of them?

Dr. SHELTON. Yes.

Chairman ANDERSON. If there is, does this sentence stand:

One must consider that even for a very large scale war——

Dr. SHELTON. The worldwide fallout.

Chairman ANDERSON. No; the worldwide hazard. You did not say anything about fallout there. There is a book that has been written called "On the Beach," and a lot of people are worried. All you have to do is take this sentence, and you can say—

Dr. Shelton says nothing will happen. It will be like a shower of ceremonial spray of some kind, and it won't hurt you at all.

Is that what you are saying?

Dr. SHELTON. I am saying that as far as the worldwide fallout hazard is concerned.

Chairman ANDERSON. You have to interpolate. This sentence will be repeated by the press as you gave it and not as you would like to have given it. You gave it "the worldwide hazard to the countries," and I believe you would find out if you went to a European, that Belgium and France and West Germany are considerably worried about the worldwide hazard to them if there is a large-scale shooting war between the Russians and some other nation. Can I say to them to quiet them down that they don't need to worry at all, nothing will happen to them?

Dr. SHELTON. No.

Chairman ANDERSON. I don't believe so, either.

Dr. SHELTON. It certainly depends on one's point of view and the proximity of that country to the closest bomb. The bomb's fallout will be no respecter of boundaries or countries.

Chairman ANDERSON. You remember when we traced the cigar shaped pattern that took place out in the shots in the Pacific that it went for 200 miles?

Dr. SHELTON. Yes, easily that far.

Chairman ANDERSON. A shot that is fired from Russia close to the coast of country A right next to the Belgians, 200 miles would go clear across all of Belgium and the Netherlands.

Dr. SHELTON. That is right.

Chairman ANDERSON. Those people should look at that with calm?

Dr. SHELTON. Certainly not, sir.

Chairman ANDERSON. I would think not.

Dr. SHELTON. They are in the local fallout area.

Chairman ANDERSON. But the statement will not be interpreted by them as local fallout area.

Dr. SHELTON. There is always a hazard of pulling a sentence out of context, I agree. If one is in the proximity of the war, there will be no respect of country boundaries.

Chairman ANDERSON. Wouldn't you agree that if there was a very large scale atomic war that nearly everybody in Europe would be affected by it?

Dr. SHELTON. Yes, sir. But, I was going to say that those familiar with "On the Beach," it is probably pure fiction from a worldwide fallout point of view.

Representative HOLIFIELD. I think the Chair should state at this time that we have to take this a segment at a time. There will be some discussion of the worldwide fallout by Dr. Machta, who is the principal witness on that point.

Dr. SHELTON. That is right.

Representative HOLIFIELD. The testimony of the present witness is directed strictly to the genetic effect. This sentence refers back to the genetic effect of the worldwide fallout. It does not refer to a pattern of attack on which the general outline contemplates testimony and which will take into consideration, not in detail as we will on the United States, for various reasons, the fact that there would be blast and fire and immediate radiation damages in any country that was hit by an attack such as this. The committee did not want to be charged with warmongering, and therefore it did not go into detail on the amount of weapons that might be dropped either in retaliation or by an enemy in attacking this country. An enemy undoubtedly would drop some on the oversea NATO bases and U.S. bases.

I think the committee should be patient with the witnesses and relate their testimony particularly to the subject under discussion. This does not mean that we should not ask clarifying questions. I hope everyone asks questions because it is very difficult to be understood in this field. I hope every member will ask questions to clarify any particular statement.

I would also like to say, Dr. Shelton, that after you look over your testimony, if you feel, in the confusion of questions, that your answers have not been clear, you will have the opportunity to put them in proper context with the question and with relation to the subject that you are discussing.

Dr. SHELTON. Yes, sir; I will take pains with that.

4. Thermal radiation

Still discussing the effects on man of a nuclear detonation, moving from the radiation area to the thermal area—like nuclear radiation, thermal radiation can have a biological effect in incapacitating a

person. The degree of incapacitation depends on the parts of the body exposed and the amount of energy received. For example, second degree burns of the hands are those which cause blistering, and are most painful, and will pretty effectively prevent work by that individual, and second degree burns of the eye area will certainly make one rather ineffective. For 1-megaton surface bursts, a person exposed within 9 miles of ground zero and with no shielding can be expected to receive second degree burns on any bare skin exposed directly to the bursts. For a 10-megaton weapon this range would be not quite three times as large in distance, about 25 miles away from a 10-megaton bomb. A person with exposed skin could expect to receive blistering, and second degree burns.

Representative HOSMER. In relation to protection against that, the areas that were clothed, would they receive any substantial damage?

Dr. SHELTON. The clothing area at this distance should minimize the burn to a blistering or sunburn type and not a blistering burn. Under clothing at these distances, the skin would have some protection and it would be like a sunburn, but not blistering. At closer distances, you can get second degree burns under clothing.

As another example, a person standing out in the open at 25 miles from a 10-megaton burst will receive blisters an all exposed skin. These second degree burns are the most difficult type to treat clinically. I am sure you will have an expert witness to cover this quite thoroughly.

Representative HOSMER. The protection factor on this type of thing is minimal.

Dr. SHELTON. Yes. All you need is something opaque between you and the bomb, any type of material, and the thermal hazard goes away down.

Representative HOLIFIELD. Dr. Shelton, I note there has been no discussion of the immediate neutrons.

Dr. SHELTON. They were included and integrated into the dose received from the prompt radiation. That last chart still on the floor showing the initial radiation resulting in probable death, has prompt gamma and prompt neutron added together into that dose. It does not matter what does it, if it kills you, and its effect on the tissue are very much the same.

5. Blast

Blast overpressure is itself not a very significant casualty agent. About 100 p.s.i. is required to have a significant effect of ruptured eardrums, for instance, and nuclear radiation, thermal radiation and fallout will almost certainly produce casualties where 100 p.s.i. can reach a man. However, the secondary effects and injuries caused by crumbling buildings, flying debris and translation of man himself are certainly very significant. Extensive blast injury can be expected at distances at which brick apartment houses collapse, and those distances were 7 miles from ground zero for a 10-megaton burst, and a little over 3 miles for a 1-megaton burst.

I believe you have a blast biology witness, Dr. White, in the later days, and I am sure he will tell you about the hazards of flying debris and in particular the hazard of flying glass. I would expect exten-

sive window damage at 25 miles from a 1-megaton burst, and it would be an extreme hazard out to about 7 miles. Don't stand behind windows in an attack. First you will get burned and then you will have fine glass splinters driven into you very deeply within distances like 7 miles from a 1-megaton burst.

Representative HOLIFIELD. Every schoolroom in the United States has tremendous expanses of glass.

Dr. SHELTON. Yes, sir.

Representative HOLIFIELD. I think this is a very important point you are bringing up, and I am sure it will be gone into in more detail when the blast witness appears before us.

Dr. SHELTON. Yes. Glass in any disaster like the Texas City disaster is one of the primary materials found in the normal home which can result in blinding and all other types of effects due to the flying small splinters of glass.

My long acquaintance and friend, Dr. White, will fully expound on the hazard of debris, and particularly flying glass.

IV. SUMMARY OF EFFECTS FOR NUCLEAR WEAPONS FOR 1 AND 10 MEGATONS

To summarize the effects of nuclear weapons, they are blast, which is primarily a damaging agent to inanimate objects such as buildings, and it does produce flying debris which is a hazard to man.

The cratering effect results in the destruction of even deep underground structures. Thermal radiation damages both humans and combustible structures and materials. Nuclear radiation, including both the initial and the local residual fallout are primarily hazards to man and animals and can deny man the use of inaminate objects. For reference, I have included in table 1 the effects that I have been discussing for the last hour or so.

TABLE I.—*Summary of effects of the assumed nuclear weapons 1 to 10 megatons*

	1 megaton	10 megatons
A. Inanimate objects:		
1. Crater (dry soil)	Radius, 650 feet Depth, 140 feet	Radius, 1,250 feet. Depth, 240 feet.
2. Brick apartment houses collapse	Radius, 3 miles	Radius, 7 miles.
3. Ignition of light kindling materials	Radius, 9 miles	Radius, 25 miles.
B. Man:		
1. Blast injury (flying debris)	Radius, 3 miles Area, 28 square miles	Radius, 7 miles. Area, 150 square miles.
2. 2d degree burns on bare skin	Radius, 9 miles Area, 250 square miles	Radius, 25 miles. Area, 2,000 square miles.
3. Initial nuclear radiation (700 r.e.m.).	Radius, 1.5 miles Area, 7 square miles	Radius, 2 miles. Area, 12.5 square miles.
4. Fallout, 15-knot winds (450 r.e.m. in 48 hours, no shielding).	40 miles downwind, 5 miles crosswind. Area, 200 square miles	150 miles downwind, 25 miles crosswind. Area, 2,500 square miles.

Moving to man, let us just repeat again, blast injury, due to flying debris, occurs out to about 3 miles for a megaton weapon, and about 7 miles for a 10-megaton weapon. The areas there are about 28 square miles and 150 respectively. The burn area is a very large area, as you see, for a 10-megaton burst, about 2,000 square miles on clear days, or when the bomb thermal is easily seen. Fallout; in this case

450 rem in 48 hours, and no shielding, occurs in an area of about 2,500-square miles for a 10-megaton weapon.

Running down the columns, you notice that 10 megatons is 10 times the energy release of 1 megaton. But notice that the effects only reach out sometimes a factor of two, sometimes a factor of three, seldom ever a factor of four for the larger yield burst. A 10-megaton yield does not reach out to 10 times the distance. The distances are rather slow functions of yield, usually a factor of two, sometimes a factor of three. This is the variation in distance of a given effect from 1 to 10 megatons.

I did not feel that in the testimony I should cover two, three, and eight megatons. They can be interpolated in between the distances given and the uncertainties of effects are probably larger than warranted by exact mathematics for the other yields.

Representative HOLIFIELD. It occurs to me, Dr. Shelton, in the responses to Mr. Hosmer's questions, and other questions from members that you might want to prepare a statement in regard to this rate dose. You might include in that the factors of difference between, let us say, 10, 100-kiloton weapons, and 1 megaton weapon and such other pertinent information as you think would clear up and remaining doubts. We realize that we cannot cover the whole field, but we will try to do the best we can.

Dr. SHELTON. I will certainly do that, sir. (See table I, p. 41.)

Representative HOLIFIELD. Are there any questions of Dr. Shelton? If not, there is one question I would like to ask you, Doctor. Is it not true that if human beings are in the blast area, it is not only the external pressure upon the human individual's body which is dangerous, but also the human being himself becomes a flying missile, and is propelled through the air until he does strike an inanimate structure?

Dr. SHELTON. That is precisely right, sir. The body is able to withstand overpressures quite well. It is the flying debris, the translation of the man himself in the hurricane-like winds that accompany the bomb. It is this sort of thing that always accompanies the blast and produces the blast casualties.

Representative HOLIFIELD. Did you have anything else to add?

Dr. SHELTON. No, sir.

Representative HOLIFIELD. Thank you very much, Dr. Shelton. It might be well for the record to show that Dr. Shelton is Technical Director of the Defense Atomic Support Agency. He has been active in the atomic energy field since 1952. During the spring of 1955 he served as technical adviser to the military effects test group at Operation Teapot, and in 1953 participated in Upshot-Knothole. He has also participated in Operation Redwing in 1956, Operation Plumbbob in 1957, and Operation Hardtack in 1958. Dr. Shelton was born in 1924. He received his bachelor of science, master's, and doctor of philosophy, all in physics from the California Institute of Technology, and prior to joining the Defense Atomic Support Agency (formerly the Armed Forces Special Weapons Project), Dr. Shelton was with the Sandia Corp. in the weapons effects field.

Thank you very much for your testimony this morning. We plan to have our next witness at 2 o'clock, Mr. Charles Shafer, from the Office of Civil Defense Mobilization.

The meeting is adjourned until 2 p.m.

(Thereupon at 12 m., a recess was taken until 2 p.m., the same day.)

AFTERNOON SESSION

Representative HOLIFIELD. The committee will be in order.

This afternoon we open the session with testimony from Dr. Charles Shafer, Office of Civil Defense and Mobilization.

Representative HOLIFIELD. I might note that Mr. Shafer has been meteorologist for the U.S. Weather Bureau from 1940 to 1957. He served with the Air Force during the war. He was in the FCDA and now in the Office of Civil Defense and Mobilization. He heads up their meteorological services in the fields of chemical, biological, and radiological defense. He testified before this committee in 1957.

Mr. Shafer, will you please come forward.

I will say to the members of the committee that copies of Mr. Shafer's presentation are a little slow in getting here. They will be in a little later and they will be distributed as soon as they arrive.

TESTIMONY OF CHARLES K. SHAFER,[1] DIRECTOR, METEOROLOGICAL OFFICE, OFFICE OF CIVIL AND DEFENSE MOBILIZATION

Mr. SHAFER. Mr. Chairman and members of the committee, may I first correct the record with regard to the title. It is mister and not doctor. I wish it were, but it is not.

This study, requested by the committee, was undertaken in order to indicate the extent and intensity of close-in radioactive fallout which might spread across the United States after a specific nuclear-attack with the meteorological conditions for a given day.

This presentation will also indicate the effects of the attack on dwellings with regard to blast and thermal factors and with regard to fallout.

To better understand the development of the fallout situation, we shall first examine the attack in greater detail. Chart No. 1 indicates the attack pattern which was developed and provided by the committee as a basis for the study. Each circle such as at Syracuse, Binghamton, Evansville, Waco, Great Falls, et cetera, represents the surface detonation of a 1 megaton nuclear weapon. There are 48 of these weapons.

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[1] Born: May 26, 1918.
Undergraduate work—New York State College at Albany, N.Y.
Graduate work—College of Engineering, New York University.
Has participated in weapons detonations during Plumbbob and Hardtack, performing: (a) Aerial and surface monitoring; (b) fallout prediction; (c) dose-depth and dose-distance relationships; (d) shelter evaluation.
1940–57, Meteorologist with U.S. Weather Bureau.
(a) On loan to U.S. Air Force during World War II (Wright-Patterson area).
(b) On loan to the United Nations for meteorological research, 1948–49.
(c) On loan to CAA and assigned at Athens, Greece, to plan rehabilitation of the Greek Weather Service, 1952–54.
(d) On loan to FCDA to assist in radiological fallout problem, 1955–57.
(e) Transferred to FCDA (now OCDM) in 1957 to head up their meteorological services in the fields of chemical, biological, and radiological defense.

Each square such as at Jacksonville Navy Base, Redstone Arsenal, Hartford, Minot, Alamogardo, Eglin Air Force Base, et cetera, represents the surface detonation of a 2 megaton nuclear weapon. There are 38 of these.

Each triangle such as at New Haven, Worcester, Toledo, Grand Rapids, Abilene, San Bernardino, et cetera, represents the surface detonation of a 3 megaton nuclear weapon. There are 44 of these.

Each half circle such at as Patrick Air Force Base, Cape Carnaveral, Savannah River, Boston, Rochester, Memphis, Oklahoma City, Denver, Berkeley, et cetera, represents the surface detonation of an 8 megaton nuclear weapon. There are 74 of these.

Each star such as at Limestone Air Force Base, New York City, Philadelphia, Baltimore, Washington, Pittsburgh, Detroit, Chicago, St. Louis, Kansas City, Dallas, Los Angeles, San Francisco, Portland, Seattle, et cetera, represents the surface detonation of a 10 megaton nuclear weapon. There are 60 of these.

By States, California has the greatest megatonnage, 19 weapons, 124 megatons. Texas has the greatest number of weapons, 24 weapons, 112 megatons. In both States the attacks are primarily on Air Force bases.

There is a marked concentration of weapons along the city complex from Washington to Boston. For example, there are 28 megatons in the Washington area, 22 in Baltimore, 20 on Philadelphia, 20 on New York City, and 22 on Boston. Actually along this line from Washington to Boston there are 275 megatons. Other areas of weapon concentration are Detroit, Chicago, and Los Angeles with 20 megatons each and the San Francisco-Oakland Bay area with 38 megatons.

The following five maps (Charts 2–6) will indicate our estimate of what the fallout situation would be across the United States 1 hour after the nuclear attack, 7 hours, 2 days, 2 weeks, and 3 months. The maps will also show our estimates of the accumulated, outside, unsheltered radiation doses at various points along the fallout patterns.

These fallout estimates are developed from the stylized dose rate patterns in the "Effects of Nuclear Weapons." The stylized dose rate patterns in this publication are based upon monitored data from multimegaton detonations in the Pacific Proving Grounds and from kiloton detonations in Nevada and the Pacific. At any specfic point in these fallout areas, the dose rate values are subject to the same uncertainties as are all quantitative fallout forecasts. However, they do have sufficient accuracy for planning purposes, i.e., sufficient accuracy to indicate the extent and intensity of the fallout problem for which we must plan survival actions.

Further, as instructed by the committee the weapon design has been assumed to be 50 percent fission–50 percent fusion. It is further assumed that about 80 percent of the radioactivity produced will come down as close in fallout during the first 2 days postattack. The meteorology selected for the preparation of the fallout charts is October 17, 1958.

On this day the average wind speed in the deep column of the atmosphere from 60,000 feet to the surface on the earth, was about 60 miles per hour in the upper Great Lakes region and the northern plains. It averaged 40 miles per hour over New England, the Middle

Atlantic States, the northern Rockies, and the Pacific Northwest. It was about 30 miles per hour in the Ohio Valley and the Southeastern States and approximately 20 miles per hour in the lower Mississippi Valley and the Southwestern States. This meteorological situation is not unusual. In fact, it is fairly typical for the fall season.

FALLOUT MAP AT H PLUS 1 HOUR (CHART 2)

This map shows our estimate of the fallout condition which would exist across the United States 1 hour postattack. The individual fallout areas would vary in length from about 40 miles in southern United States to 80 miles in the upper Great Lakes regions depending upon the average wind speed in the deep column of the atmosphere at each particular location. Also, the widths of these individual fallout patterns would vary from about 20 miles to over 50 miles depending primarily upon the size of weapon. The dose rates along the border of the areas at H+1 would be about 10 roentgens per hour. Moving inward from the green area the dose rates would increase rapidly, exceeding 3,000 roentgens per hour in the inner zones which are shaded red. At some points in these red zones immediately downwind of the ground zero locations of the larger weapons, the dose rates might be as high as 10,000 roentgens per hour at H+1. This would particularly apply in the northeastern part of the United States where there is considerable overlap of fallout. In the shaded zones the dose rates would exceed 100 roentgens per hour and in the blue shaded zones they would exceed 1,000 roentgens per hour.

FALLOUT CONDITION AT H+7 HOURS (CHART 3)

This map indicates our estimate of the fallout condition which would exist 7 hours after the attack. By this time approximately 30 percent of the national land area would have fallout conditions exceeding 1 roentgen per hour. This is the dose rate which would exist along the border of the green shaded areas. Moving inward from this border the dose rates would increase quite rapidly and in the red shaded areas they could exceed 300 roentgens per hour at H+7 hours. It should be noted that in the area from Norfolk west to Cincinnati to Indianapolis to Chicago, east to Detroit to Buffalo to Albany to Boston, and back down the coast to Norfolk there is virtually no area where the dose rate is less than 1 roentgen per hour at H+7 hours.

FALLOUT CONDITION AT D+2 DAYS (CHART 4)

This map indicates our estimate of the fallout conditions which would exist across the United States 2 days postattack. At this time approximately 46 percent of the national land area would be covered by fallout intensities exceeding one-tenth of a roentgen per hour. This is the dose rate which would exist along the borders of the green shaded areas. As one moves inward from these borders, the dose rate would increase quite rapidly and in the inner red shaded areas it would exceed 30 roentgens per hour at D+2 days. Again it should be noted that in the area from Norfolk to Cincinnati to Chicago to Detroit to Boston and back to Norfolk there are rela-

tively few locations where dose rates are less than 1 roentgen per hour at D+2 days.

At this time—that is, at D+2 days—the dose rates exceed one-tenth of a roentgen per hour on 46 percent of the national land area; 1 roentgen per hour on 15 percent of the national land area; 10 roentgens per hour on 5.8 percent of the national land area; and 30 roentgens per hour on 1.5 percent of the national land area.

At about D+2 days radiological decay would begin to predominate over further fallout deposition and the borders of the 0.1 roentgen per hour does rate contours would begin a gradual shrinking or retreat back toward the ground zeros. This would result in a decrease of the total area of the United States covered by dose rates exceeding one-tenth of a roentgen per hour after D+2 days.

FALLOUT CONDITION AT D+2 WEEKS (CHART 5)

This map shows our estimate of the fallout condition which would exist at D+2 weeks. On this map the borders of the yellow areas now indicate the location of the one-tenth roentgen per hour dose rate contour. At this time, D+2 weeks, only 15 percent of the national land area would have fallout intensities exceeding one-tenth of a roentgen per hour. This compares to 46 percent of the national land area which had a fallout intensity exceeding one-tenth of a roentgen per hour at D+2 days. It should be noted at D+2 weeks the dose rates in the inner red zones would still exceed 3 roentgens per hour.

FALLOUT CONDITION AT D+3 MONTHS (CHART 6)

This reduction in radiation intensities would continue as a result of radiological decay. This map indicates our estimate of the fallout condition which would exist across the United States at D±3 months. At this time, only about 5.8 percent of the national land area would be affected by fallout intensities exceeding one-tenth of a roentgen per hour. These areas shaded in red and blue on this particular chart represent the locations where the dose rates were in excess of 1000 roentgens per hour when normalized back to H+1 hour.

Further, these might very well represent the areas which would have to be evacuated a few days postattack and abandoned for periods of months to possibly a year.

I use the word "year" very advisedly. This is an area of tremendous uncertainty. So months to a year, or years, would possibly be the best term to be used. Obviously, the period of abandonment would be determined by the effectiveness of decontamination and the rapidity of radiological decay. In these fallout estimates we have assumed that the mixed fission products, comprising the fallout, would decay in accord with the time to the minus 1.2 decay principle. That is, we assumed that for every sevenfold increase in time, the radiation would decay by a factor of 10. For example, a dose rate of 1000 roentgens per hour at H+1 hour would decay to 100 roentgens per hour at H+7 hours; to 10 roentgens per hour at H+49 hours or about 2 days; and to 1 roentgens per hour at D+14 days or D+2 weeks. Beyond 2 to 3 months postattack, the radioactive material would probably decay at a different rate. However, for planning purposes this assumed decay principle is sufficiently accurate if

the limitations or uncertainties are recognized and taken into account as we do in our planning in OCDM.

Representative HOLIFIELD. May I ask you at this time, Mr. Shafer, have you also plotted the accumulated radioactive dose for the representive years?

Mr. SHAFER. Yes, sir; I have. I shall come back to that in a moment if I may, sir.

A word of caution: As indicated before, we have taken these materials from the Effects of Nuclear Weapons. These stylized, cigar-shaped patterns are scaled from the pattern in the effects of Nuclear Weapons for weapons of different yields and they are sufficiently accurate for planning purposes. However, we know from monitoring reports of specific fallout areas that the fallout patterns are not idealized as indicated on this map; but rather, there would be irregularities and there would be hotspots, which we take into account in our planning in OCDM. However, Dr. Machta intends to discuss this in detail so I shall not discuss it further.

May I again have the fallout map for D+2 days (Chart 4).

In order to indicate the accumulated, unsheltered radiation dose, we will go back to the map of the estimated fallout condition at D+2 days. Each of these individual fallout areas has the arrival time of fallout indicated by dashed lines. For example, about 50 miles downwind of the 10 megaton attack on Ellsworth Air Force Base you will note a dashed line labeled 1, meaning that fallout had spread that far downwind 1 hour after detonation.

A second dashed line farther downwind labeled 7 and another labeled 12 indicates the distance to which fallout would spread from the attack 7 and 12 hours after detonation. There are similar dashed lines or isochrones as we call them, on each of the fallout areas. The table on the top of the map shows the accumulated, unsheltered radiation doses in each of the colored zones at these dashed lines or isochrones. For example, in the red zone at the H+1 dashed line, the accumulated, unsheltered radiation dose would exceed 8,100 roentgens during the first 2 days. In the blue shaded area along this same isochrone the accumulated, unsheltered radiation dose would range from 2,700 roentgens along the outer border to 8,100 roentgens along the inner border next to the red shaded area. Likewise, in the yellow zone the accumulated, unsheltered radiation dose during the first 2 days would range from 270 to 2,700 roentgens and in the green shaded area it would range from 27 to about 270 roentgens. Further downwind at the H+7 dotted line or isochrone the accumulated, unsheltered radiation dose would be less than one-half that at the H±1 isochrone.

Also, at the H+12 isochrone the accumulated, unsheltered radiation does would be slightly more than one-fourth the dose at the H+1 isochrone. Thus, the further downwind of ground zero the less in general will be the accumulated, unsheltered radiation dose, except for the hotspots. Also, this same generalization would hold with regard to distances crosswind or upwind of ground zero.

The subsequent map, the fallout conditions at D+2 weeks, shows an additional 2,100 roentgens of radiation exposure in the red area at the H+1 isochrone or a total accumulated, unsheltered radiation dose of over 10,000 roentgens in the red areas during the first 2 weeks

postattack. Likewise, even after 2 weeks the outside radiation dose continues to accumulate. On the D+3 months chart we see that the accumulated, unsheltered radiation dose along this same isochrone in the red areas has now increased to over 12,000 roentgens. Thus, it is obvious that the close in radiation hazard from fallout persists for a very long period of time, months to possibly a year or more postattack.

As mentioned before, we computed these doses on the basis of the $t^{-1.2}$ decay rate. Later data by NRDL has indicated that this assumption underestimates the radiation dose during the early periods postattack and overestimates the dose during the later periods.

Representative HOLIFIELD. We had some testimony on this point in our bomb test radioactive fallout hearings. What effect would the later information have on the charts that have been given us and why was not the later information used in the preparation of these charts?

Mr. SHAFFER. Mr. Chairman, Dr. Triffet plans to discuss this. I have merely pointed out that $t^{-1.2}$ indicates an increase of radiation dose of 2,000 roentgens from 2 weeks to 3 months in this case. The NRDL data would decrease this perhaps to 1,000 or 1,500 roentgens rather than the 2,000 roentgens additional accumulation. We have included it on the chart simply to show that there is a continuing long-term problem, but the numbers are probably a bit on the high side.

Representative HOLIFIELD. Then we will have testimony that will go into detail on this point later?

Mr. SHAFER. This is my understanding, sir.

Representative HOSMER. May I ask, Mr. Chairman, will we also have an extrapolation, for instance, in the large green areas where the accumulated dose would be from 7.5 to 75 at H+12?

Mr. SHAFER. Yes. The dose at H+12 arrival time would vary from 7.5 to 75 roentgens.

Representative HOSMER. That would be for somebody standing outside in the open.

Mr. SHAFER. That is correct.

Representative HOSMER. What would be the effect if he went inside?

Mr. SHAFER. You are one step ahead of me, sir. That is my next point.

Representative HOSMER. That is fine.

Mr. SHAFER. It should be noted that these values represent our estimate of the accumulated, unsheltered radiation dose during the periods indicated on each map. Obviously, the radiation dose to the individuals located in these areas will be decreased by the effectiveness of the fallout shelter in which they are located. For example, remaining on the first floor of an average home would decrease these radiation doses to one-half the indicated values. Also, remaining in the central portion of the basement of the home would decrease these radiation doses to about one-tenth; and remaining in the corner of the home basement would reduce these radiation doses to perhaps one-twentieth of the values indicated. A basement concrete block shelter 8 inches thick built in the corner of a basement would provide the fallout protection needed in most areas of the Nation. This should reduce the unsheltered, accumulated radiation dose up to about one-two hundredfiftieths of the values indicated on the map.

Note that in the most severe fallout zones; that is, the red areas, the radiation dose to people in this type of shelter would be generally less than 100 roentgens during the first 2 weeks. In the other colored areas it would be considerably less than 100 roentgens. It should be stressed that this type of shelter is for fallout protection only, not for protection against blast and thermal effects.

Mr. Chairman, we have recently prepared and distributed a publication to advise the American public how to construct this type of family fallout shelter at a cost of $150 to $200 per family. We also have in this publication instructions on how to build a shelter if you are not fortunate enough to have a basement. Five million of these booklets are currently being distributed. Eventually, we plan to distribute 50 million of them—one to every householder in the United States.

Further, it should be emphasized that these maps represent our estimate of the fallout conditions which would exist under the given attack pattern when applied to the winds and weather of one specific day; namely, October 17, 1958. If a different attack pattern had been used or if this attack had been applied to the winds and weather of another day, this fallout situation would probably develop quite differently. Areas which appear to be in the clear on this particular fallout situation might well have a serious fallout condition if a different attack pattern or wind condition had been used.

Next, Mr. Chairman, we plan to present the effects of this attack on dwellings. Do you want me to proceed with this or do you have further questions on the fallout maps?

Representative HOLIFIELD. What is the committee's pleasure? Are there any questions at this time?

Senator HICKENLOOPER. I just want to get clear, Mr. Shafer. Your statements on the increasing rate of radiation is entirely due to fallout, is that correct?

Mr. SHAFER. That is correct, sir, with regard to the accumulated outside radiation dose.

Senator HICKENLOOPER. Not increasing intensity?

Mr. SHAFER. The intensity decreases with time but the radiation dose accumulates with the passage of time.

Senator HICKENLOOPER. Accumulating radiation dose?

Mr. SHAFER. That is correct, sir. For instance, the fallout map shows 8,100 roentgens outside, accumulated dose during the first 2 days in the red areas. On the next chart (Chart 5), D+2 weeks, this goes up to 10,000 roentgens and then at 3 months it goes up to 12,000 roentgens.

Senator HICKENLOOPER. So that the intensity of the radiation dosage decreases rapidly from the time of burst, but the cumulative dose of radiation increases actually because of the continued fallout in these particular areas over a period of time.

Mr. SHAFER. Not necessarily because of more fallout coming down, sir, but because the fallout on the surface of the ground does not decay all at one time. It decays slowly over a long period of time. So as long as the fallout on the ground does not completely decay there will be additional radiation exposure.

Senator HICKENLOOPER. So it is both the additional fallout that comes down and the fallout that has already struck the earth.

Mr. SHAFER. That is correct. This would be the case where the overlap is very heavy in the Northeast.

Senator HICKENLOOPER. Thank you.

Senator ANDERSON. You mentioned this booklet about this shelter that can be built in the basement.

Mr. SHAFER. That is correct, sir.

Senator ANDERSON. This morning we had some testimony about a two-story house getting a blast that would drop all the top stories and all the furniture and everything down in the basement. Do you think this shelter would do much good with all the house coming down?

Mr. SHAFER. Outside the heavy blast area; yes, sir, it would. Let us take this isolated fallout situation where there is no overlap, this is Ellsworth Air Force Base. True, this shelter would not provide the blast protection needed in Rapid City, S. Dak. However, beyond the blast area, beyond about 7 miles from ground zero, this shelter would have considerable value. If you will note, this red area of very intense fallout extends almost down to Nebraska some 120 miles, sir. So once beyond the heavy blast area this type fallout shelter would provide the protection needed and prevent people from being exposed to these extremely high doses. Instead of 8,100 roentgens the first 2 days exposure to people in these fallout shelters might be a matter of 30 to 40 roentgens. Not in the heavy blast areas, though. Only in the fallout areas. About 96 million people in the United States live outside areas of likely blast damage and therefore would have adequate protection with this type of shelter.

Senator ANDERSON. What percentage of the homes now being built have basements?

Mr. SHAFER. I can't answer that, sir. I do know that most of the homes in the southern half of the country do not have basements. Most of those in the northern half do have. In this particular publication we also have instructions on how to construct a fallout shelter if you are not fortunate enough to have a basement.

Representative WESTLAND. Based on that map you have there give me an estimate of the number of people in terms of percentage that would be dead at the end of 2 days from Miami to Boston.

Representative HOLIFIELD. Those figures, I will say to the gentleman, are being computed by the Office of Civil Defense and Mobilization and will be presented later. Not only in total amounts for the United States, but also for the different cities of the United States.

Representative HOSMER. Mr. Shafer, what you have told us essentially is that if you are in the area where the bomb detonates you probably cannot do much to protect yourself against the blast and the thermal and other immediate effects.

Mr. SHAFER. With this type of shelter in the areas of heavy blast damage, that is correct.

Representative HOSMER. But if you are not within that immediate area there are efforts which you can take and precautions that will enable you to survive?

Mr. SHAFER. Yes, and at a very low cost—$150 to $200 per dwelling.

Representative HOSMER. I note most of your area is not in the heavy radiation area but in the lighter radiation area and that is what underlies your statement.

Mr. SHAFER. That is correct. If you will look at the accumulated unsheltered doses you will see that these are fatal doses in the red, blue, and yellow areas without shelter. These have to be attenuated by fallout shelter if people are to survive. Otherwise, the people in these areas will be exposed to lethal amounts of radiation. If you look at this complex in northwestern United States which I pointed out before, there are very few green areas in here, which means that under this particular condition everyone in this area would need a fair degree of fallout shelter in order to survive.

Representative HOSMER. What you are telling us essentially is that we don't have to look at that map and slash our wrists, because there is hope.

Mr. SHAFER. That is correct. There is very much hope, if people will take the precautions we have and are advocating.

Senator JACKSON. Of course, if the enemy utilizes chemical agents and BW in concert with thermonuclear weapons, the shelter problem is a little difficult.

Representative HOLIFIELD. I think the record should show what BW means, Senator.

Senator JACKSON. Biological warfare and chemical agents.

Mr. SHAFER. That is correct, sir. We at this particular time were requested only to comment on radiological warfare. However, what you have said is true.

Senator JACKSON. The reason I ask the question, I think over on the House side today this very point is being brought out by General Stubbs in a little different way. General Stubbs is the head of Chemical Warfare, Department of the Army.

Mr. SHAFER. Within OCDM we are planning on countermeasures for CW and BW. We are stockpiling organizational masks and other defensive materials.

Senator JACKSON. CW means chemical warfare.

Mr. SHAFER. That is correct, sir.

Senator JACKSON. And BW is biological warfare.

Mr. SHAFER. Since I am not prepared to discuss this, Mr. Chairman, I would rather stick to the radiological situation which we have prepared for presentation.

Representative HOLIFIELD. I would like to also say that the number of megatons used in this study does not necessarily indicate the amount that would be used on the United States or the times or problems involved in delivery. There might be a lesser attack or there might be a great deal larger attack. So it is impossible to study every phase, or every degree of attack. What we are going to try to do is to use the ground rules of this particular type of attack. Then with the evidence before us any person that is not satisfied that they have had enough can extrapolate to something bigger. Or, if you want a smaller attack you can extrapolate back to a smaller attack.

Mr. SHAFER. I would like to caution again on the misuse of this particular chart. I would not like to see any one come up and look at it and say, yes, here is Manchester; this is a safe place; I shall move there. Because with a different weapon attack, different wind conditions, Manchester might very well have a serious fallout condi-

tion. This is one meteorological condition, and one attack pattern.

Shall I proceed?

Representative HOLIFIELD. Proceed, Mr. Shafer.

Representative WESTLAND. May I ask one further question?

Representative HOLIFIELD. Mr. Westland.

Representative WESTLAND. How did you happen to choose the setup that you did?

Mr. SHAFER. This attack pattern, sir.

Representative WESTLAND. Yes.

Mr. SHAFER. It was provided by the committee.

Representative HOLIFIELD. The attack pattern, as shown in the handouts, was established as a reasonable type of attack after a great deal of consultation on the part of the members of the subcommittee and the staff with people who are experts in the field. This study, for instance, is approximately 1,500 megatons on the United States whereas I believe a previous study by the Civil Defense Administration went as high as 2,500.

Is that not true, Mr. Shafer?

Mr. SHAFER. We have studied attacks of this size and other sizes, sir.

Representative HOLIFIELD. Can you give at this time the different operation alerts and the amounts used in those attacks from memory?

Mr. SHAFER. Not very well from memory. I believe Opal 57 was about 384 megatons, and Opals 58 and 59 about 675 megatons.

Representative HOLIFIELD. There was one at 2,500.

Mr. SHAFER. This was not an operation alert. This was a special internal exercise which we called Sentinel.

Representative HOLIFIELD. Was the 2,500 study effects made public?

Mr. SHAFER. Yes, to this particular committee in 1957, sir.

Shall I proceed, sir?

Representative HOLIFIELD. Yes.

Mr. SHAFER. This table shows the effects of the attack on dwellings within the United States. It indicates the numbers of units receiving severe, moderate, and light blast damage. Further, it shows the total units outside the blast areas which would be under fallout intensities exceeding 3,000 roentgen-hours; 1,000 to 3,000 roentgen-hours; 100 to 1,000 roentgen-hours and less than 100 roentgen-hours when normalized to H+1 hour.

Effects on dwelling

	Units
Blast effects:	
Severe damage	11,800,000
Moderate damage	8,100,000
Light damage	1,500,000
Fallout effects:	
Greater than:	
3,000 r/hr	500,000
1,000–3,000 r/hr	2,100,000
100–1,000 r/hr	10,400,000
Less than: 100 r/hr	11,700,000

It should be noted that 11.8 million dwellings would suffer severe damage—to the extent that they would not be salvageable. This is approximately one-fourth of the dwellings in the United States. And an additional 8.1 million dwellings or about 17 percent of the national

total would suffer moderate damage and would have to be vacated for major repairs. Further, 1.5 million dwellings or about 3 percent would suffer light damage and could be repaired without being vacated. This totals 21.4 million dwellings damaged.

Representative HOLIFIELD. How does that rate relate to the total number of dwellings?

Mr. SHAFER. This is a little less than half, sir.

Representative HOSMER. Give us the number.

Mr. SHAFER. 46.1 million dwellings total in the United States and this is 21.4 million dwellings damaged, a little less than 50 percent. Let us say 45 percent.

Approximately 500,000 dwellings, outside the areas of blast damage, would be affected by fallout intensities exceeding 3,000 r/hr. normalized to H+1 hour. These are the red shaded zones on the fallout maps. The homes in these zones would have to be evacuated and abandoned for probably a year, perhaps longer.

About 2.1 million dwellings, outside the areas of blast damage, had fallout intensities varying between 1,000 and 3,000 r/hr. when normalized to H±1 hour. These are the blue shaded areas on the fallout maps. The homes in these zones would have to be evacuated and abandoned for a period for several months to perhaps a year in some instances. Actually, the period of abandonment would depend upon this effectiveness of decontamination and the rapidity of radiological decay. However, this subject is scheduled for discussion later by another group.

Approximately 10.4 million dwellings, outside the areas of blast damage, had fallout intensities varying between 100 and 1,000 hr. when normalized to H+1 hour. These are the yellow shaded zones on the fallout maps. If major decontamination efforts were undertaken most of the homes in these yellow areas could be made available for living by 60 days' postattack.

About 11.7 million dwellings, outside the areas of blast damage, had fallout intensities less than 100 r./hr. when normalized to H+1 hour. These are the green areas and unshaded zones on the fallout maps. Although a serious radiation problem would exist in the inner portions of the green shaded zones, most of the homes in these areas could become available by 2 weeks' postattack.

This totals 24.7 million dwellings outside of the area of blast damage affected by fallout.

Let us look at this chart in a little more detail to determine how serious the problem would be. This plus this, that is the homes beyond repair, the homes vacated for major repairs, plus those which would be denied to us for a period of months to possibly a year because of fallout, total about 22.5 million units; or approximately 50 percent of the dwelling units across the United States would be denied use for 60 days to some indefinite period of time.

This completes my formal presentation, sir. If you have questions I will be very happy to try to answer them.

Representative HOLIFIELD. Please stand by for questions.

Are there any questions?

Representative HOSMER. Mr. Chairman, I don't have questions at this point but the witness has mentioned on two or three occasions

what percentage of dwellings were damaged or suffered in another way. I think it would be helpful if his table could show in all cases a percentage figure to total units so that we can have some concept thereby of what he is talking about in addition to just the bare numbers.

Representative HOLIFIELD. I think that is a good suggestion. In your testimony where you refer to specific numbers, include also the percentages and submit a corrected copy for the permanent record.

Mr. SHAFER. Yes, sir.

Representative HOLIFIELD. Senator Hickenlooper.

Senator HICKENLOOPER. It is my understanding that you have made an arbitrary assumption of a certain number of bombs striking this country, or a certain number of megatons.

Mr. SHAFER. We did not make this decision. The committee made this decision, sir.

Senator HICKENLOOPER. Regardless of who made it, this is based on the assumption of a certain number of megatons striking this country?

Mr. SHAFER. That is right, sir.

Senator HICKENLOOPER. This may or may not be an actual case. To me, at least, it would be completely a wrong impression to have it go out that in case of an atomic attack this is what would happen to the United States, because this might or might not happen to the United States.

Mr. SHAFER. With regard to the fallout, I tried to indicate the variability factor that would exist, sir.

Senator HICKENLOOPER. In other words, if it were a much smaller amount of megatonnage that hit the United States there would be a very substantial reduction in this?

Mr. SHAFER. That is correct, sir.

Senator HICKENLOOPER. As a matter of fact, you have assumed a fairly substantial amount of megatonnage hitting the United States.

Mr. SHAFER. The committee has, sir.

Senator HICKENLOOPER. I am not saying you originated it. I am saying your assumptions are based on that. We will grant that the committee gave you the assumptions to go on. I am not holding you to any particular assumptions except to explore what would happen based upon the assumptions which they gave you.

Representative HOLIFIELD. Again let the Chair state that the OCDM is not responsible for setting up this assumption. The Chair, assisted by expert consultants, set up the assumption. The assumption is considered, by almost all military people that have been talked to, as being a realistic assumption. I read this morning a letter from Lt. Gen. James M. Gavin, in which he said, "I consider your assumptions to be entirely realistic and well within the capabilities of a potential aggressor." This does not mean that this type of attack may hit the United States. It might be any degree. It might be five times as great, it might be one-fifth. What we have done here is to take even a more modest type of attack than the Federal Civil Defense Administration used in its 2,500 megaton study which it made.

Representative HOSMER. Mr. Chairman, I think it is probably important to realize that also we might not be attacked at all. This is a hypothetical situation to get an estimate of that if it happened. We certainly by reason of holding these hearings are not predicting that it will.

Representative HOLIFIELD. That is right. This has no relation to any particular plan because, as far as this committee knows, there is no plan for any attack on the United States at this time. We had to set a definite figure with which to make the study.

As I explained before, it can be extrapolated downward or upward by those who are interested.

Senator HICKENLOOPER. Mr. Chairman, just to make it clear, I am not quarreling with the assumption. I am only calling attention to the danger that the country may feel in case of any kind of attack that this is what would happen. As a matter of fact, this is based upon an arbitrary assumption and one must start some place. You must have some kind of a basis. You must have some kind of assumption. But this is an arbitrary selection of the quantity of an attack, and you are merely giving what would happen under those specific assumed conditions.

Representative HOLIFIELD. That is exactly correct, and I thank the Senator for clarifying this point.

Mr. SHAFER. May I point out one further thing, Mr. Chairman. In this particular attack as I indicated earlier, there is a very heavy concentration of weapons near the coastal areas from Washington northeast to Boston. I think you noticed in the development of the fallout situation that the greater bulk of the fallout from those weapons went into the Atlantic Ocean. Extreme southeastern New England, Long Island, and the Delmarvian Peninsula have been seriously affected. Had these same weapons been detonated further inland the close-in fallout situation in eastern United States would have been worse.

Representative HOLIFIELD. Would you comment on the magnitude of the effect of fires on dwellings? You have given us the damage to dwellings. Does that include those damaged by fire as well as blast and does it include fire in the case of the moderately damaged dwellings?

Mr. SHAFER. That is correct. These include blast and thermal effects.

Representative HOLIFIELD. Are there any further questions?

If not, we thank you very much, Mr. Shafer.

Mr. SHAFER. Thank you, sir.

Representative HOLIFIELD. We are pleased to have before us as our next witness Dr. Machta of the U.S. Weather Bureau.

Dr. Machta has been before us before and we have always enjoyed having his professional testimony.

The record will show your biography, Dr. Machta, so that the readers may know your background of experience and qualifications. I think it is well enough known to this committee that we will just ask you to proceed with your presentation.

TESTIMONY OF LESTER MACHTA,[1] U.S. WEATHER BUREAU

Dr. MACHTA. Thank you, Mr. Chairman.

I think we are all aware of the fact that from our past experience all atomic tests which have local fallout also produce worldwide fallout. There are two main problems in computing this worldwide fallout. First, we must know how much radioactivity is available for dispersal and, second, we must know how it is distributed. It is the purpose of this discussion to describe the assumptions used in preparing the maps showing the worldwide fallout. In addition, I will describe, in words, the fate of the radioactive carbon 14 created by a nuclear war.

First the production of radioactive debris will be presented.

For purposes of illustration and because of its familiarity, we shall deal with strontium 90 fallout. Later, we can apply the results to other long-lived radionuclides.

The attack on the United States of approximately 1,500 megatons is augmented by 2,500 megatons elsewhere in the world for a total of about 4,000 megatons. Fifty percent of the energy from each weapon was assumed to be derived from fission, for a total of 2,000 megatons of energy equivalent of fission products. Each megaton of fission energy creates 100,000 curies of strontium 90. Thus, the 2,000 megatons energy equivalent of fission produces 200 million curies of strontium 90. These curies are divided as follows: 80 percent is deposited in local fallout, 15 percent in stratospheric fallout and 5 percent in tropospheric fallout. About 20 percent of the 200 million curies are available for worldwide dispersal.

In the United States, the local fallout deposition has been calculated by OCDM based on the AFSWP idealized model. Since estimates of the total (local plus worldwide) as well as the worldwide strontium 90 fallout are desired in the United States, it is necessary to convert the external dose to the strontium 90 which is associated with the gamma emitting fission products. We assume that 1 roentgen per hour at 1 hour is equivalent to 100 millicuries per square mile of strontium 90. This conversion is based on the "Effects of Nuclear Weapons" plus a small correction for shielding of particles in the actual ground since it is not a perfectly smooth surface.

Second, we will distribute the worldwide fallout.

The tropospheric strontium 90 is carried rapidly around the world in a generally west-to-east direction. It spreads in a north-south direction slowly so that the peak fallout is roughly in the latitude of the war area. The stratospheric fallout is deposited entirely in the Northern Hemisphere peaked at about 45° north and tapering off

[1] Meteorologist, U.S. Weather Bureau; associated with atomic energy and meteorology since coming to Washington in 1948, now Chief of the Special Projects Section. Born in New York, N.Y., in 1919, graduated cum laude from Brooklyn College in 1939. His meteorological training includes graduate work at New York University (master of arts, 1946) and at Massachusetts Institute of Technology (doctor of science, 1948). During the war he taught meteorology in both a civilian and military capacity for the Air Force. Member of Sigma Xi, Pi Mu Epsilon, the American Meteorological Society, and the American Geophysical Society. Recently been given a gold medal for exceptional service by the Department of Commerce. Publications in the meteorological literature are numerous and, in recent times, include papers on atomic energy and meteorology. Has been a member of many important Government committees, including the Advisory Committee passing on the meteorological safety of tests in Nevada. Has been instrumental in making the worldwide measurement of radioactivity part of the International Geophysical Year program.

toward the Equator and North Pole. Both tropospheric and stratospheric fallout are brought down mainly with falling rain or snow; most of the tropospheric within about a month or so after the war and the stratospheric within a few months to a few years. The observed rainfall for the first month after mid-October 1958, was used in estimating the tropospheric fallout and the average annual rainfall, weighted slightly in favor of spring rains, was the basis for the stratospheric deposition pattern.

The peak accumulation of strontium 90 in most places will probably occur in about 3–5 years after the attack. During this period about 10 percent of the strontium 90 made will have decayed. Within the areas of heaviest level fallout, where levels are greater than about 10,000 millicuries per square mile of strontium 90 (see fig. 2) radioactive decay will be greater than the added tropospheric and stratospheric fallout and the peak value will occur at the time of the attack. Beyond 3 to 5 years following the war, the decrease in deposited strontium 90 fallout is principally due to radioactive decay; 2½ percent of the strontium 90 being lost each year.

Next, we will discuss the maps. Figure 1 is a polar stereographic projection of the Northern Hemisphere showing isolines of worldwide strontium 90 deposition in millicuries per square mile. This map does not show the local fallout on the United States or other countries. The highest line appearing on the map is 1,400 millicuries per square mile in the western North Atlantic. The more intense fallout here is due to heavy rainfall and to the proximity to the numerous bombs dropped on the Northeast United States.

The southwestern United States with lower rainfall shows smaller than average fallout values. In round terms, the entire North Temperate Zone will receive about 1,000 millicuries per square mile from worldwide fallout. This, for reference, can be compared with about 75 millicuries per square mile as the highest observed fallout value in the United States up to last fall.

Representative HOLIFIELD. At this point will you explain for the record what a millicurie is?

Dr. MACHTA. A millicurie is one-thousandth of a curie. A curie is the amount of radioactivity which is emitted from one gram of radium. It is an amount of radioactivity.

Representative HOLIFIELD. At this point I will say that all of these figures you are giving us today apply to the total global readings and not to the local fallouts which we had this morning.

Dr. MACHTA. That is right. We will show a map in a moment indicating a sum of the local plus the global fallout.

It should be noted that the worldwide pattern is not very sensitive to where in the North Temperate Zone the attack took place. Thus, if all 4,000 megatons were dropped on the United States then the picture over Europe would be very similar.

Figure 2 is a map of strontium 90 fallout on the United States with both local and worldwide fallout. The levels of strontium 90 deposition connected with the local fallout far exceed the worldwide fallout except at the edges of the local fallout patterns. Thus, many of the strontium 90 isolines are similar to the gamma dose rate isolines given by OCDM.

The innermost isoline within which there is heavy red shading contains over 300,000 millicuries of strontium 90 per square mile, or over 300 times the mean Temperate Zone worldwide fallout for this exercise.

It would take over 250 years for the strontium 90 level within the 300,000 millicuries per square mile line to be reduced to 1,000 millicuries per square mile, for example, if only decay were considered.

Representative HOLIFIELD. Could I stop you at that point and ask what the present reading from bomb test fallout is in millicuries per square mile?

Dr. MACHTA. Yes. Our strontium 90 fallout values in the United States average, I would say, about 50 millicuries per square mile. I refer to last October when measurements were made in the United States and not at the present time. The highest value was reported as about 75 millicuries per square mile at Rapid City, S. Dak. We are now talking in terms of an average over the United States of about a thousand millicuries per square mile from global fallout alone.

Representative HOLIFIELD. For strontium 90?

Dr. MACHTA. That is right.

Representative HOLIFIELD. Now you are giving figures on other isotopes?

Dr. MACHTA. Yes.

Representative HOSMER. Just before you do that, your statement implies that there is something in addition to the decay considered.

Dr. MACHTA. Yes.

Representative HOSMER. Will you, or one of the other witnesses, explain that?

Dr. MACHTA. I think Dr. Reitemeier can go into this more. There is some question whether strontium 90 penetrates deeper into the soil and is thus unavailable to the plants.

One may readily convert the isolines on the maps from strontium 90 to cesium 137 by simply multiplying each number by 2. About twice as many cesium 137 atoms as strontium 90 atoms are formed by the nuclear explosives. The half-life of the two substances are almost identical and it is assumed that they do not fractionate with respect to one another, that is, there is no tendency for more of one than the other to be deposited in local rather than worldwide fallout.

Representative HOLIFIELD. Would it be well to say, at this time, that the half-life of both of these is approximately 28 years?

Dr. MACHTA. That is correct.

Next, we can discuss carbon 14. The radioactive carbon 14 which presents a genetic hazard following a nuclear war is present in the form of carbon dioxide when in the atmosphere. The natural carbon dioxide of the air also contains cosmic ray carbon 14 radioactivity in small amounts. The carbon dioxide becomes carbon in our bodies, from which it is possible to compute the very small dosage of ionizing radiation and other damage. If the level of carbon 14 is raised, the dosage to man will also increase. As has been pointed out by many people, production of carbon 14 occurs with thermonuclear as well as fission bombs, that is, "clean" as well as "dirty" bombs.

There is considerable uncertainty in the amount of carbon 14 created during the nuclear war since it depends on the nature of the nuclear devices. For purposes of this exercise, we have used the recent AEC conversion based on experience from U.S. weapon tests. Thus, approximately 8×10^{29} carbon 14 atoms are added to the atmosphere, mainly the stratosphere. Within a few years after the attack, they will be mixed with the troposphere. At this time, before mixing with the Southern Hemisphere and the surface layers of the oceans is complete, the carbon 14 in the ground level Northern Hemisphere air may rise to about 20 times natural cosmic ray carbon 14 background. After several years to tens of years later, mainly as a result of mixing with the surface layers of the oceans, the excess carbon 14 will be halved. Then gradually over a period of several hundred years of mixing with the large carbon reservoir of the deep oceans will reduce the bomb-created carbon 14 in the lower atmosphere to less than 50 percent of natural background. Continued radioactive decay will very slowly decrease the excess carbon 14 after mixing is complete. The half-life of carbon 14 is 5,600 years so that the decay is indeed slow.

SUMMARY

1. Levels of strontium 90 and cesium 137 worldwide fallout average about 1,000 and 2,000 millicuries per square mile, respectively, in the North Temperate Zone.
2. Areas of heavy local fallout possess much higher long-lived fission products than the worldwide fallout—by factors up to perhaps 500 times more. Regions in which the local fallout is significantly greater than worldwide fallout constitute perhaps 10 to 20 percent of the area of the United States.
3. The carbon 14 created by bombs may temporarily raise the radioactive carbon contest of ground level air to as high as 20 times natural background shortly after the war. But after several hundreds of years the carbon 14 excess will be reduced to no more than 50 percent of background and then decay slowly to lower values.

Representative HOLIFIELD. Thank you, Dr. Machta.

Are there any questions of Dr. Machta on his presentation?

Chairman ANDERSON. I would just like to ask one question.

Doctor, how about the short-lived isotopes like iodine 131 and barium?

Dr. MACHTA. As a result of the fact that the tests take place in the north temperate latitude, the material of stratospheric origin will be deposited much more quickly than from the tests which we have conducted in the Pacific area. The result is that there will be a greater hazard from iodine 131 and other short-lived fission products from this war than from an equivalent megatonnage from our tests in the Pacific.

Chairman ANDERSON. Thank you.

Representative HOLIFIELD. Are there any further questions? If not, thank you very much, Dr. Machta, for your presentation.

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We will hear from Dr. Machta again on a paper later on in this series of hearings.

Our next witness is Dr. Terry Triffet, from the U.S. Naval Radiological Defense Laboratory.

I may say for the benefit of the record that the U.S. Naval Radiological Defense Laboratory, which is located at Hunters Point, Calif., is an organization of some 600 scientists and other professional personnel that have been busy working on the problems of weapons effects with particular emphasis in the field of radiation, both on human beings, animals, and different types of physical materials, such as building materials and textiles, and all other types of materials. It is probably the center of our greatest depository for radiological laboratory information.

The managers of the laboratory have chosen Dr. Triffet to give us this part of the presentation. Dr. Triffet, you may proceed.

STATEMENT OF DR. TERRY TRIFFET,[1] U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY, HUNTERS POINT, CALIF.

Dr. TRIFFET. Mr. Chairman, gentlemen of the committee, I have prepared a formal statement which I would like to submit for the record.

Representative HOLIFIELD. It will be received.

(The statement referred to follows:)

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[1] Profession: Research engineer. Date and place of birth: June 10, 1922, Enid, Okla. Parents: R. B. Triffet, Enid, Okla. Married: Millicent McMaster, May 26, 1946. Children: Patricia A. Triffet. Education: B.A. (with honors) Human., University of Oklahoma, 1945; B.S. (with special honors) engineering, University of Colorado, 1948; M.S., engineering, University of Colorado, 1950; Ph. D., engineering, Stanford University, 1957. Professional and honorary societies: APS, ASCE, Society of Rheology, AAAS, Sigma Xi, Phi Beta Kappa, Tau Beta Pi. Work history: 1947–50, instructor, College of Engineering, University of Colorado; 1950–55, rocket research and development, U.S. Naval Ordnance Test Station, China Lake, Calif.: 1955 to present, Head, Radiological Effects Branch, U.S. Naval Radiological Defense Laboratory, San Francisco, Calif. Publications: Several papers and technical reports on effects of radiations on materials, properties of fallout, and radiological effects. Present residence: Palo Alto, Calif.

BASIC PROPERTIES AND EFFECTS OF FALLOUT

Composition of Debris

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Introduction

The following discussion will feature the properties of the fallout which would be produced by a nuclear explosion of about 5 megatons (50% fission - 50% fusion) occurring under two different conditions:

(1) on the surface of silicate sand soil in a industrial area,

(2) on the surface of a deep ocean water harbor among a group of ships.

These two conditions (Figures 1-1, 1-2) were selected both because they represent likely conditions for the attack pattern specified, and because it is known that they would produce widely different kinds of fallout. Most other important conditions, such as detonation in a shallow harbor (Figure 1-3), will probably produce fallout whose properties lie somewhere in between these extremes.

Another reason for picking these two conditions is that they are those from the given attack pattern to which existing data most nearly apply.[1,2,3,4] Several megaton yield range detonations have, for example, taken place on

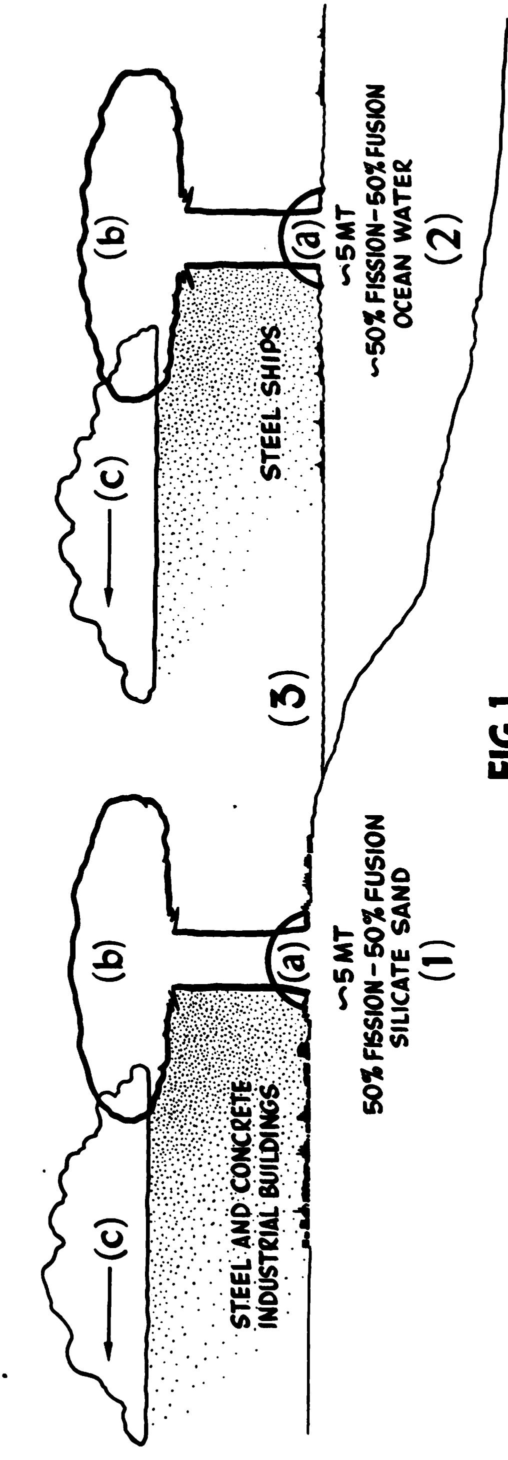

FIG.1
ASSUMED DETONATION CONDITIONS

steel barges anchored in the lagoons of atolls in the Eniwetok Proving Grounds. Although these barges were ballasted with coral sand, and were sometimes located in water shallow enough to permit bottom material to be sucked up by the explosion, the total amount of sand was usually small relative to the amount of ocean water involved. It will be assumed for purposes of this study that the fallout from these events is representative of that for the deep harbor condition cited above.

There have been no U.S. test detonations in the megaton range on silicate soil, however. Those in the right yield range have taken place on coral sand in the Eniwetok Proving Grounds, and those on the right kind of soil at the Nevada Test Site have all been in the kiloton yield range. Under these conditions it can only be assumed that the physical properties of the fallout for the land surface burst referred to above will resemble those of the Nevada fallout, while the magnitude of the effects and all other characteristics will be more like those of the Pacific events. It should be clearly understood that this is, at best, a questionable assumption, since both the yield of the bomb and the type of soil on which it is detonated critically affect the resulting fallout.

It is also true that substantial quantities of steel have been present in most past test explosions -- the supporting tower for the majority of air bursts, the barge for water surface bursts, and large quantities of experimental equipment in all cases. There is reason to believe, as will

appear later, that metals in general and iron in particular play a singularly important role in fallout formation processes. This is an additional reason why it was specified above that the land surface burst would occur in an industrial area and the water surface burst among a group of ships. The nature of the fallout which would result from bursts on bare soil or unobstructed water with no significant amount of metal present has not been definitely established at the present time.

Besides the type of weapon, its total yield, and the nature of the environmental material, one other factor strongly influences the character of the fallout: the height of the burst above the surface. A pure airburst, for reasons which will become clear later, creates only very small particles which contribute to world-wide fallout but produces nearly no local fallout. A moderately deep underground or underwater burst on the other hand produces almost nothing but highly localized fallout. The surface conditions selected for this study will maximize local fallout areas and yet produce considerable amounts of world-wide fallout.

If for one reason or another a burst does not occur on the surface during the attack, different effects are to be expected. A deep underwater burst will, for example, produce a pulsating bubble filled with radioactive products. This will lead after a short delay to a surface eruption and a rapidly expanding ring of contaminated mist a thousand or more feet tall; little if any fallout in the usual sense of the word will take place.[5] No

attempt will be made to cover the effects of other burst heights in the following discussion. Before proceeding with descriptions of the fallout for the two conditions chosen, however, it is desirable to explain in a general way the overall processes of fallout formation and deposition.

Basic Phenomena

When the nucleus of a heavy atom like uranium fissions, or the nuclei of two light atoms such as hydrogen fuse, part of the mass of the original system is converted into energy. This appears in the form of the energy of motion of the product atoms, the excitation of the electrons of the atoms, and the energies of the nuclear radiations and particles, such as gamma-rays and neutrons, which are emitted. When the number of atoms fissioning or fusing is small or spread out in time, the resulting energy can be dissipated gradually in the surrounding medium; but when the number of atoms is large, and they fission or fuse almost simultaneously, a shock wave is formed in the medium as a means of dissipating the energy. Large quantities of neutrons, electrons and gamma-rays are also released from the many nuclear reactions, and intense heat and light rays are generated as the rapidly moving atoms and excited electrons drop to lower energy levels. Taken all together, these phenomena constitute a nuclear explosion (Figure 2).

There are several significant differences between fission and fusion

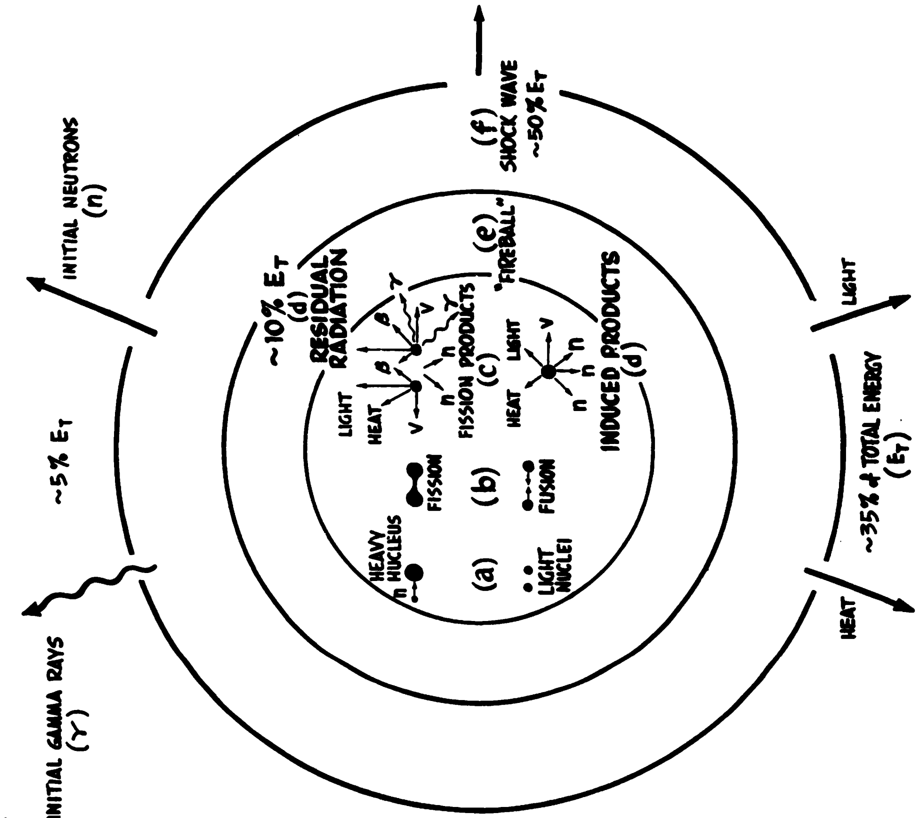

FIG. 2 NUCLEAR EXPLOSION PROCESSES

explosions, however. In the former most of the neutrons released are utilized internally to sustain the fission process, while in the latter a large part of the neutrons appear externally. This means that there are far more neutrons, which are capable of rendering certain materials in the bomb and surrounding environment radioactive (the sodium in the salt of seawater, for example), available from fusion weapons than from fission weapons.[6] On the other hand the end products of fusion are harmless or only mildly radioactive gases, while fission produces radioactive products which must then decay to more stable forms by the emission of nuclear radiations. There are over 40 ways in which a heavy nucleus of uranium or plutonium can divide in fission, leading to the production of 80 to 90 primary radioactive products (Figure 3). It is the residual radiations from these fission products and the materials activated by neutron irradiation, after they have been dispersed by the dynamic processes of the explosion, which constitute the fallout hazard.

It is to be emphasized that the fusion process is capable of producing sizeable quantities of induced radioactive products. Added to this, fusion bombs must be initiated by a fission trigger, and may contain uranium which can be activated or fissioned by the neutrons of fusion.[7] Thus fusion weapons, sometimes called "clean weapons", are actually capable of producing large quantities of radioactive fallout. They can only be considered "clean" relative to pure fission weapons, much as grey might be considered

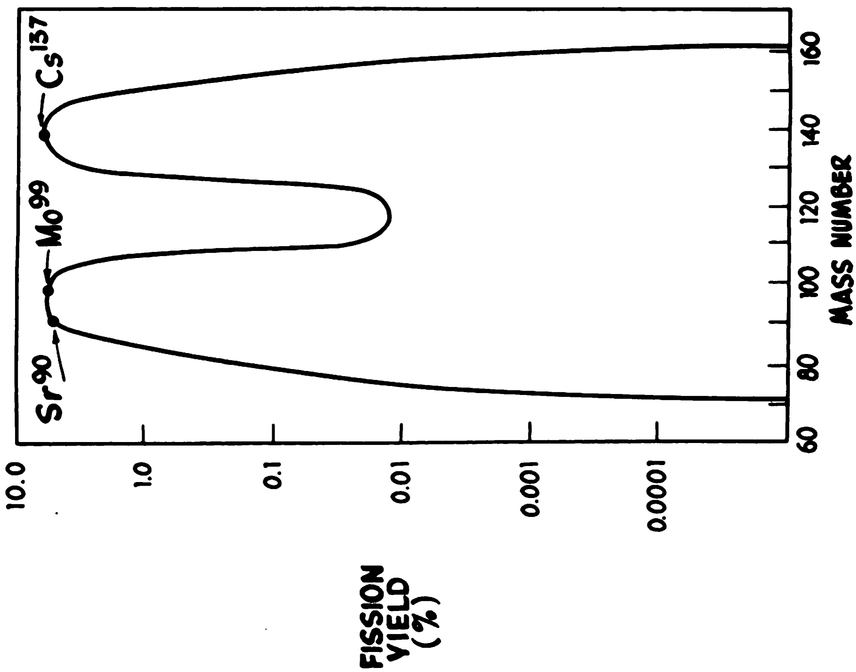

FIG. 3
FISSION PRODUCTS

light relative to black.

Approximately 50% of the total energy of a fission bomb is usually thought to be dissipated in the shock wave and about 35% radiated as heat and light[8], although these proportions are recognized to vary in different burst environments. The remaining 15% would then appear in the form of nuclear radiations-roughly 5% being emitted initially, either directly from the fissioning atoms or from the fission products contained in the fireball, with the remaining 10% being available for residual radiation (Figure 2). Certain recent work indicates that, almost regardless of the type of weapon, as much as 50% of the total energy could be dissipated as heat and light, with about 35% going to shock; since, however, the $\sim$15% going to nuclear radiations is the principal concern here, this subject will not be pursued further. There are situations where initial radiations could pose a more serious hazard at close distances than blast or thermal effects, but this is ordinarily not the case. For this reason the following discussion will be concentrated entirely on that $\sim$ 10% of the bomb's energy which takes the form of residual radiation.

This residual radiation is, of course, associated with contaminated particles. During the early stages of the explosion, while the energy of the fissioning or fusing atoms is being transferred outward

through successive layers of environmental material, the so-called "fire-ball" is produced. Since a third or more of the bomb's energy is left behind in this fireball in the form of atomic or molecular motion, its internal temperature is very high -- several hundreds of thousands of degrees centigrade. The bomb and everything in its immediate vicinity is vaporized; in fact toward the center of the explosion, molecules are ripped apart and the electrons may even be completely stripped from the atoms (Figure 4a).

As the fireball cools, the violent internal motion subsides; electrons, atoms and molecules recombine; and, eventually, condensation begins. This proceeds in the order of the boiling points of the materials present in the fireball -- those having higher boiling points, like iron, condensing first and those having lower boiling points remaining in a gaseous state until later (Figure 4b). During the cooling process, which is of the order of seconds for megaton bursts, large quantities of soil or ocean water will be drawn into the fireball. At first the temperature will be high enough to vaporize this too, but finally it will drop to the point where the soil grains from the land surface burst will only be melted (Figure 4c).

Such, then, is the early environment of the radioactive atoms produced by fission or neutron activation, and much of their subsequent history is determined by this environment. These also condense as a function of their boiling points; but, since only small quantities are involved, they probably condense for the most part on other particles, which exist in greater

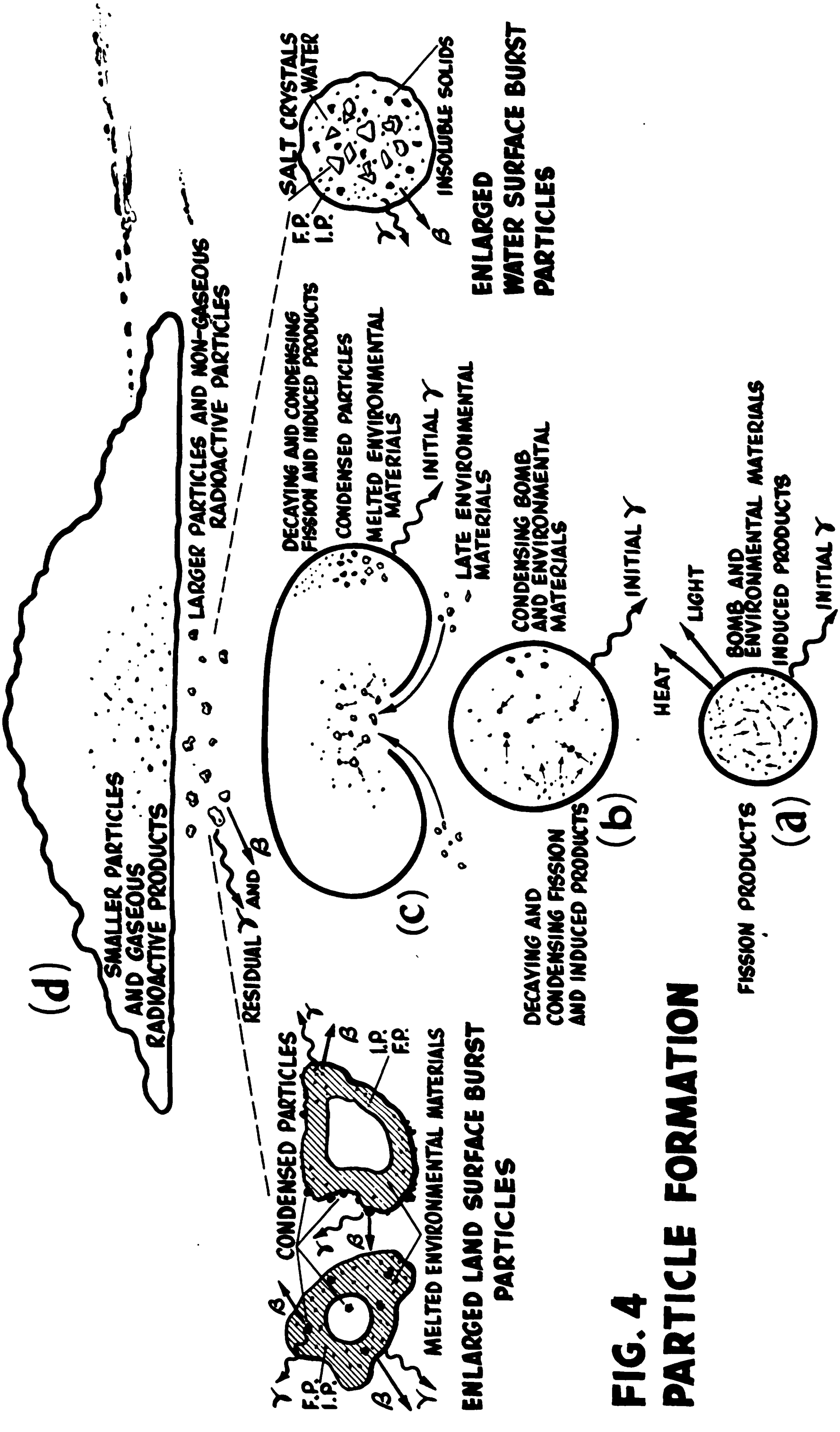

FIG. 4
PARTICLE FORMATION

numbers, in the general temperature range from 2000° to 2800° centigrade. Metals, because of their high boiling points, may provide such particles at early times, while melted soil droplets could provide them at later times.[9] This means that part of the radioactive atoms, particularly those which condense earliest, may become bound to small metallic particles (Figure 4b), which may themselves collide with and become trapped in the larger liquid soil particles (Figure 4c). Some of the remaining atoms will also condense directly on soil particles and other available materials. These larger particles then fall from the cloud to constitute the local fallout (Figure 4d).

Part of the radioactive atoms are noble gases, however, and thus do not become attached to other particles until they have decayed to more reactive kinds of atoms -- by which time most of the larger particles have already fallen out. The result is a depletion of the decay products of these gases in the local fallout and a corresponding enrichment of the decay products in the small particles which tend to remain aloft longer and be deposited at greater distances.[10] This process, known as fractionation, is an important one since it has been observed to occur for several important radioactive products in the fallout from land surface bursts -- including strontium-90, which is a decay product of the noble gas krypton, and cesium-137, which also has gaseous precursors and is one of the principal gamma-ray emitters at very late times.[1,11]

Water surface bursts on the other hand appear to be unfractionated in many important radioactive products and only slightly fractionated in others.[1] The reasons for this are closely related to the condensation processes in the cloud, and may result from more of the radioactive gas atoms decaying and condensing on small particles of metals and sea salts before water droplets can form on condensed salt nuclei, collect some of the smaller particles, and grow large enough to fall out of the cloud.[12] This surmise seems reasonable in any event in view of the lower boiling points of the components of seawater, as opposed to soil, and the observed characteristics of the fallout from such shots -- which consists of clusters of salt crystals loosely bound together with water and containing small quantities of insoluble solids.[9]

Circulation processes in the fireball and early cloud also play an important role in fallout formation, since they determine the locations and concentrations of the various materials during condensation. Present theory pictures first a rapidly-rotating, doughnut-shaped ring containing all of the radioactive products and other materials initially vaporized by the explosion. This operates to help draw environmental materials into the contaminating cloud; it also determines the distribution of radioactive and inert material which exists when the energy of rotation is lost and consequently influences the ultimate distribution of the fallout on the ground.

Local fallout from the cloud continues until only the small particles defined as world-wide fallout (ordinarily less than about 0.02 millimeter

in diameter) are left. The question then is: how much of the total radioactivity, as well as of certain specific radioactive products like strontium-90 and cesium-137, produced by the bomb is deposited locally, and how much remains available for world-wide fallout. To really answer this question will require more complete measurements than have ever been made. The results of the most recent attempt[11] will be quoted later; but it should be emphasized here that, because of fractionation, world-wide fallout from both land and water surface bursts may be enriched in such products.

If one were standing just outside the range of blast and thermal damage, downwind (with respect to the high-level winds) from a megaton land surface burst of the kind assumed, what would he experience during fallout arrival? First of all he would receive a radiation dose from the penetrating, long-range gamma-rays emitted by the fallout particles when they had descended to within about 1000 ft from him. This part of the total dose is often referred to as transit radiation, and it is important to note that it can be delivered to a given point even though the actual particles may be blown by the point and deposited elsewhere.[5]

A few minutes after the burst he would become aware of a rain of relatively large particles, glassy in appearance and varying from yellow to black in color, falling all around him. These would range from several

millimeters to perhaps 1/2 millimeter in diameter,[13] with the largest particles carrying the most radioactivity,[14] and would be clearly visible against most backgrounds[15,16] (Visual Aid 1, demonstrating ∽ 1000 r/hr fallout). The overall impression might be much like being in a mild desert sandstorm. While this was happening the concentration of the material passing through the air near him and the gamma radiation dose he was receiving would be building up steeply to a level of 1000 r/hr or more (Figure 5a); also the average energy of the gamma rays, reflected in penetrating power, would probably be higher at these early times (∽ 20 min).[17] After about the same length of time it took for the particles to arrive in the first place,[18] the rain of large particles would diminish; and radioactive decay would begin to predominate, as shown in the figure.[1] It is to be noted that at first, because of the presence of induced products, the dose rate would probably not decrease as fast as the average usually estimated[8] for mixed fission products ($\propto t^{-1.2}$), while later it would drop much more rapidly due to an overall decrease in the ionizing power of the radiation[3,16,19,20] (Figure 6; note logarithmic scale). This decay might be interrupted by the late arrival of groups of particles from higher altitudes if the high-level winds reverse themselves. These large particles would not present a serious inhalation hazard, could be easily brushed off clothes and skin, and once on the ground would tend to resist movement by surface winds.

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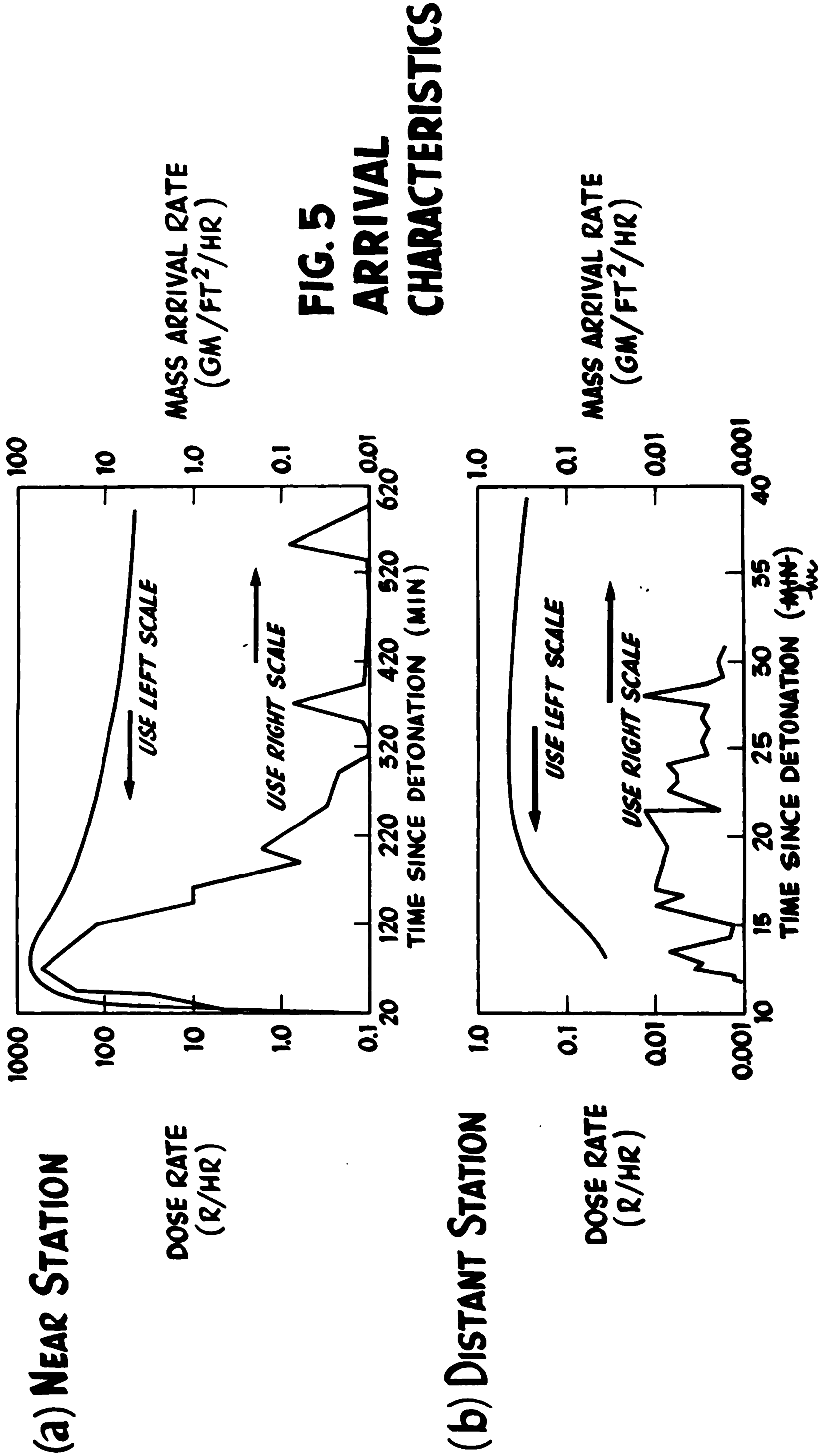
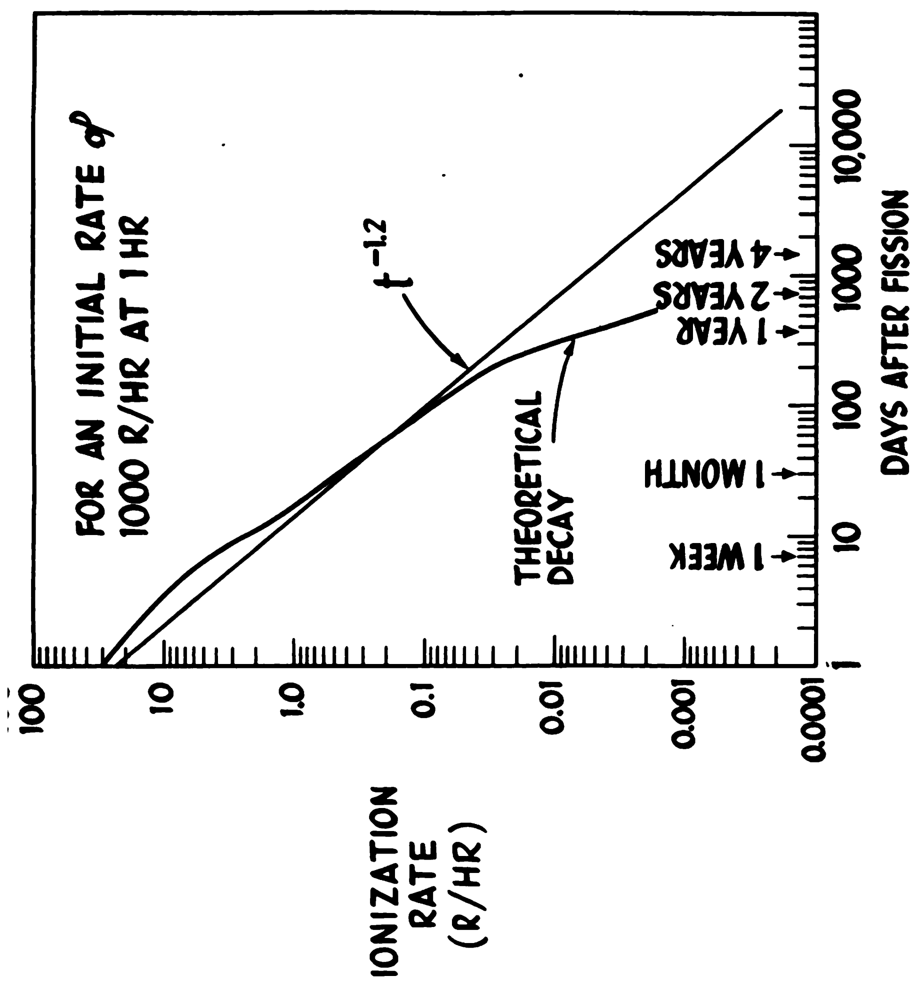


FIG. 5
ARRIVAL CHARACTERISTICS

FIG. 6
RADIOACTIVE DECAY RATE



If on the other hand one were standing so far downwind from ground zero that he could see the flash and cloud from the burst but could not hear it, his experience would be quite different. After some much longer interval of time, perhaps even several hours, a disperse cloud of fine particles would begin to settle out around him. These particles might range in diameter from about 0.1 to 0.02 millimeter, again with the largest being the most active,[14] and would be almost entirely invisible; they would, however, be of the same general type as the larger particles[15,21] (Visual Aid 2, demonstrating ~1-100 r/hr fallout). The concentration of material passing through the air and the radiation dose he was receiving would buildup gradually (Figure 5b), probably reaching a peak rate less than 1 r/hr at about twice the arrival time.[18] At this time (~ 20 hr) the average energy of the gamma-rays would probably be lower and their penetrating power less.[17] The dose rate would then decrease in a slightly irregular fashion over a long period of time, representing the effects of radioactive decay interrupted by late fallout arrival.[1,3] These small particles would represent an inhalation hazard and could not be as easily removed from skin, clothes and other types of solid surfaces. On the ground they would be subject to redistribution by the wind in the same way as the fine dust in the soil.

In case the burst occurred on an ocean surface instead of on land, the proportions of the particles would be different but the buildup charac-

teristics, as reflected in the curves of Figures 5a and 5b, would be much the same. As indicated earlier, the fallout particles would consist of clusters of salt crystals containing a small amount of insoluble material and held together with a little water. These particles probably leave the cloud as ice pellets, but continuously change their size by evaporation and condensation as they fall through different zones in the atmosphere. In any event they tend to be quite uniform in size when they arrive -- varying between about 0.1 and 0.3 millimeter in diameter -- and would be virtually invisible.[12] They would present an inhalation hazard in any location and would be very difficult to remove from most surfaces.

Figure 7a illustrates the appearance of the overall local area which might be contaminated by the fallout from a land surface burst of about 5 megatons. These are isodose rate contours for one hour constructed as best possible from actual test measurements.[22] Locations similar to those just discussed are indicated (Near and Distant Stations) and representative contours for a land surface burst in the low kiloton range are shown for comparison[4] (Figure 7b).

There are two particularly important points to notice about the contours for the megaton burst. The first is that they are highly irregular, and the second is that they contain isolated regions of higher radiation intensity at considerable distances from ground zero. Both of these are due largely to the fact that the winds at higher altitudes were blowing in various

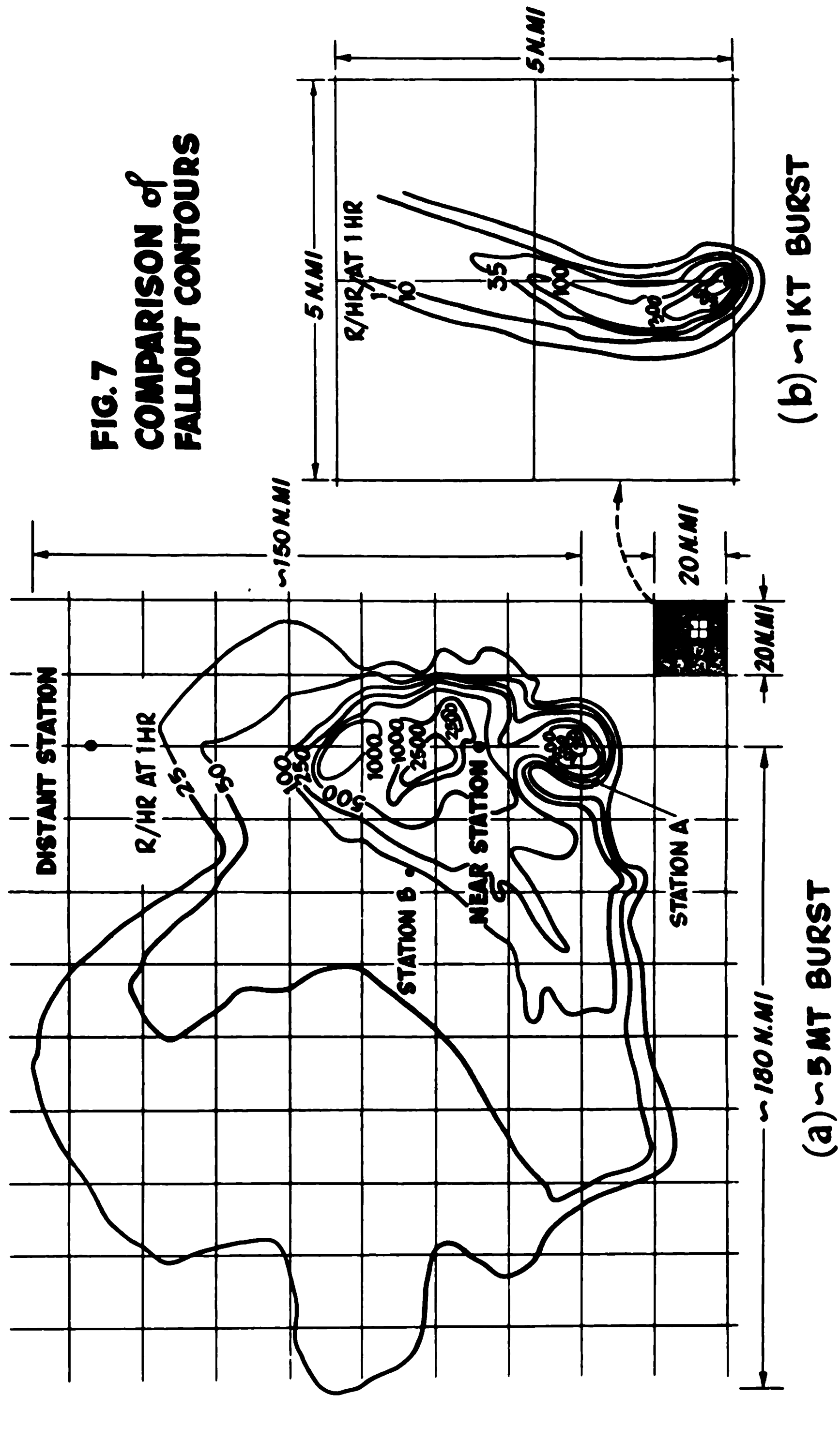


FIG. 7
COMPARISON of
FALLOUT CONTOURS

directions with different speeds following the shot. To obtain the smooth simplified contours usually shown requires simplified wind structures, which often do not exist. Although for prediction purposes it may be necessary to assume a simple wind structure and show idealized contours, it should be borne in mind that the real situation is apt to be very different. As may be seen, the same characteristics may be present to a lesser extent in kiloton burst contours, even though they will be less well-defined. The evidence is clear that, if a varying wind structure exists, the fallout pattern for megaton bursts can be such that widely different radiation doses can be received in closely adjacent areas. Notice, for example, that radiation fields less than 25 r/hr and greater than 2500 r/hr exist within relatively short distances of the Near Station in Figure 7a.

The remainder of this statement will be devoted to summarizing the estimated properties of the fallout for the two cases selected. Before doing so, however, it might be well to take advantage of the preceding discussion to bring out two points which sometimes cause confusion.

It should be clear from the foregoing development that contaminated particles and radiations from contaminated particles are two different things. The particles are contaminated in the sense that they carry radioactive atoms which are disintegrating and emitting nuclear radiations. A contaminated particle emitting gamma-rays might well be compared with an ordinary bulb emitting light. The bulb like the particle is a substantial

physical object, while the light and the gamma-rays are concentrations of pure energy. The farther one moves away from a lighted bulb, the less light he receives, and this is also true of the radiations from a fallout particle. While gamma-rays are considerably more penetrating than light, there are other nuclear radiations (alpha and beta particles) which are even less so and constitute no hazard except at very close distances.

Perhaps this will also make it clear that external and internal radiation hazards are two different things. If the source of the radiation, such as an X-ray machine or a fallout particle, is some distance away from the body of an observer, he will receive only the long-range X-rays or gamma-rays -- thus constituting an external radiation hazard. If, however, the source of the radiation is inside his body, as in the case of a fallout particle which has been inhaled or swallowed, he will receive both the long and short range radiations -- thus creating an internal radiation hazard. Certain radioactive products, such as strontium-90 and carbon-14, emit only short range radiations and consequently pose little or no extern[al] hazard. They do, however, pose a serious internal hazard, and this point should never be neglected in estimating the dangers of radioactive fallout.

Estimates of Fallout Properties

The following estimates were derived to provide values needed for the present study and are presented in the form of definite numbers where

possible to avoid vagueness. While they are based on the best experimental data and theoretical results available at the present time, they are nevertheless interpretive rather than literal -- sometimes utilizing what appears to be good data from a single test and other times combining the results of many tests and analyses. The data and results are also far from complete and, as explained earlier, may not even be strictly applicable in some cases. It is urged that all possible caution be exercised in the use of the stated values, and that the references indicated in the preceding discussion be studied before each important application. In general only those references which are essential, and which have appeared since the first congressional hearings on this subject, have been listed.

TABLE 1

ARRIVAL CHARACTERISTICS OF LAND SURFACE BURST FALLOUT

Characteristics	Station A ($\sim$ 8 mi downwind)	Station B ($\sim$ 60 mi downwind)
Time of Arrival	$\sim$ 0.25 hr since detonation	$\sim$ 7 hr since detonation
Time of Peak	$\sim$ 1.5 "	$\sim$ 13.5 "
Time of Cessation	$\sim$ 6 "	$\sim$ 16 "
Rate of Arrival	See Fig. 8a	See Fig. 8b
Peak Dose Rate	$\sim$ 40 r/hr	$\sim$ 0.25 r/hr
Total Mass Deposited	$\sim$ 4.5 gm/ft^2	$\sim$ 0.06 gm/ft^2
Total Radioactivity Deposited	$\sim$ 2.7 x 10^{15} fiss/ft^2	$\sim$ 9.5 x 10^{13} fiss/ft^2

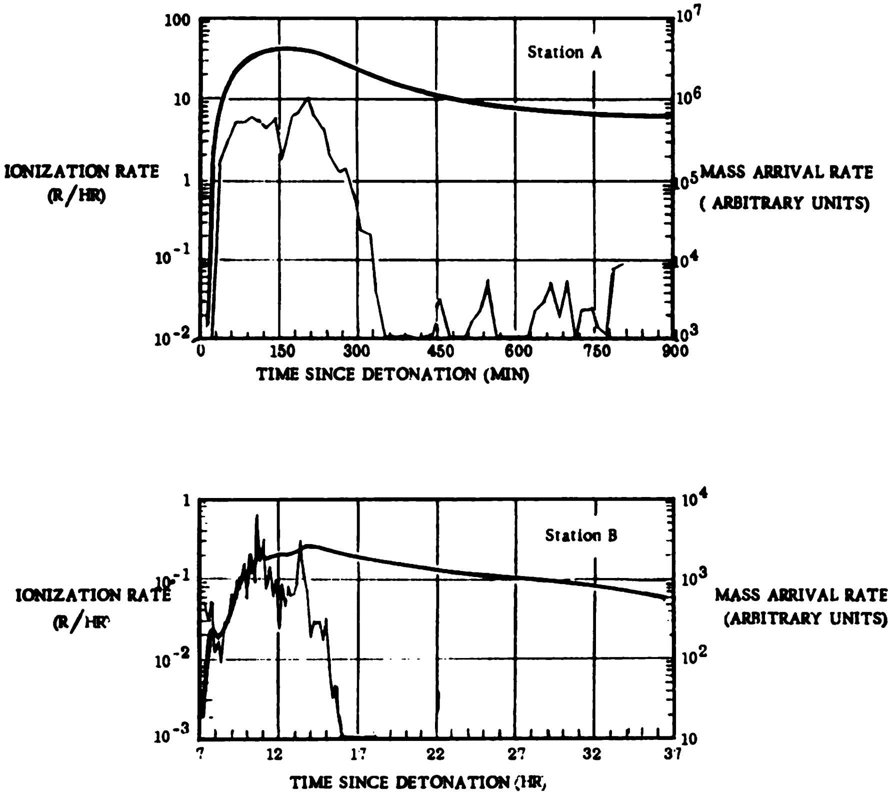


FIGURE 8 LAND SURFACE BURST FALLOUT RATE OF ARRIVAL

TABLE 2

PHYSICAL PROPERTIES OF LAND SURFACE BURST FALLOUT

Properties of Particles*	Station A (~8 mi downwind)	Station B (~60 mi downwind)
General Description	Melted, glassy solid containing air bubbles and mineral grains.	
Range of Diameters	~ 0.075 to 1.5 millimeter	~ 0.050 to 0.30 millimeter
Predominant Size	~ 0.35 millimeter in diameter	~ 0.10 millimeter in diameter
Color	Transparent to opaque, pale green or yellow to brown or black.	
Shape	Spherical to irregular.	
Specific Gravity	~ 1.4 - 2.6 gm/cm^3	
Distribution of Radioactivity	Irregularly throughout.	
Relation of Radioactivity to Size	$A \propto D_{max}^{\sim 3}$, but with the range of A increasing with D_{max}.	

* Based on properties of particles from kiloton bursts on silicate sand; all other information derived from megaton bursts on coral sand.

CHEMICAL AND RADIOCHEMICAL PROPERTIES OF LAND SURFACE BURST FALLOUT

Properties	Station A (∽8 mi downwind)	Station B (∽60 mi downwind)
Principal Components	Silicates, iron oxide.	
Relative Solubility	Less than 3% of the radioactivity soluble by leaching for several days with water.	
Principal Fission Gamma Emitters		
1-2 hr	Cs, Te, I, Nb	
13-14 hr	I, Y, Nb, Sr	
1 yr	Nb, Zr, Pr, Ba	
Beta Emitter	Sr^{90}	
Principal Induced Gamma Emitters		
1-2 hr	U^{239}, Np^{239}, Na^{24}	
13-14 hr	Np^{239}, Na^{24}, U^{237}	
1 yr	Co^{60}, Mn^{54}, Co^{58}	
Beta Emitter	C^{14}	
Relative Fractionation (Mo^{99})		
Important Products	Sr^{90}, Cs^{137}	Sr^{90}, Cs^{137}
% Depletion	∽80 ∽85	50-65 55-65
Initial Partition-% in Local Fallout		
% Total Fissions (Mo^{99})	90-95	
% Important Products	Sr^{90}, Cs^{137} 45-70 10-30	

TABLE 4

RADIATION CHARACTERISTICS OF LAND SURFACE BURST FALLOUT

Characteristics	Station A (∽ 8 mi downwind)	Station B (∽ 60 mi downwind)
Ionization Decay Rate	See Fig. 9	See Fig. 9
Average Energy		
1 hr	--	∽ 1.0 mev
2 hr	--	0.95
1/2 day	--	0.60
1 day	--	0.40
1 week	∽ 0.25 mev	0.35
1 mo	0.45	0.65
2 mo	0.55	0.65
1 yr	--	0.55

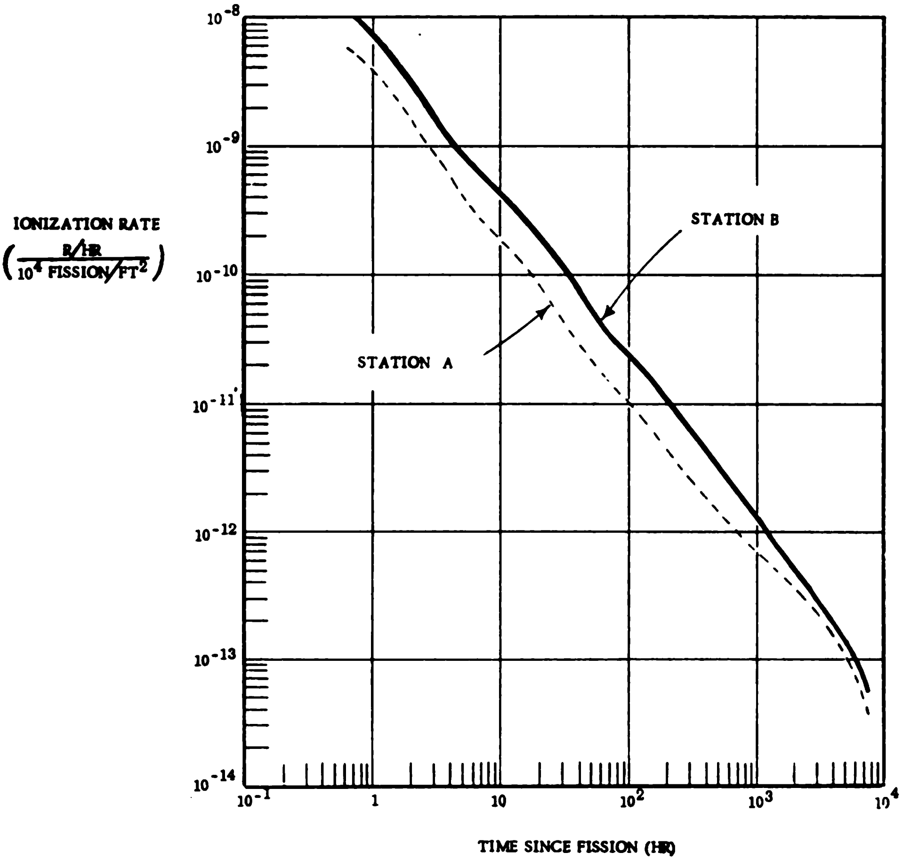


FIGURE 9 LAND SURFACE BURST RADIOACTIVE DECAY RATE

TABLE 5

ARRIVAL CHARACTERISTICS OF WATER SURFACE BURST FALLOUT

Characteristics	Station A* ($\sim$ 7 mi downwind)	Station B* ($\sim$ 22 mi downwind)
Time of Arrival	$\sim$ 0.20 hr since detonation	$\sim$ 2.3 hr since detonation
Time of Peak	$\sim$ 0.65 "	$\sim$ 6 "
Time of Cessation	$\sim$ 3 "	$\sim$ 16 "
Rate of Arrival	See Fig. 10a	See Fig. 10b
Peak Dose Rate	$\sim$ 8.5 r/hr	$\sim$ 1.5 r/hr
Total Mass Deposited	$\sim$ 5.1 gm/ft^2	$\sim$ 1.4 gm/ft^2
Total Radioactivity Deposited	$\sim$ 5.7 x 10^{14} fiss/ft^2	$\sim$ 1.5 x 10^{14} fiss/ft^2

* Contours not shown; similar to Fig. 7a.

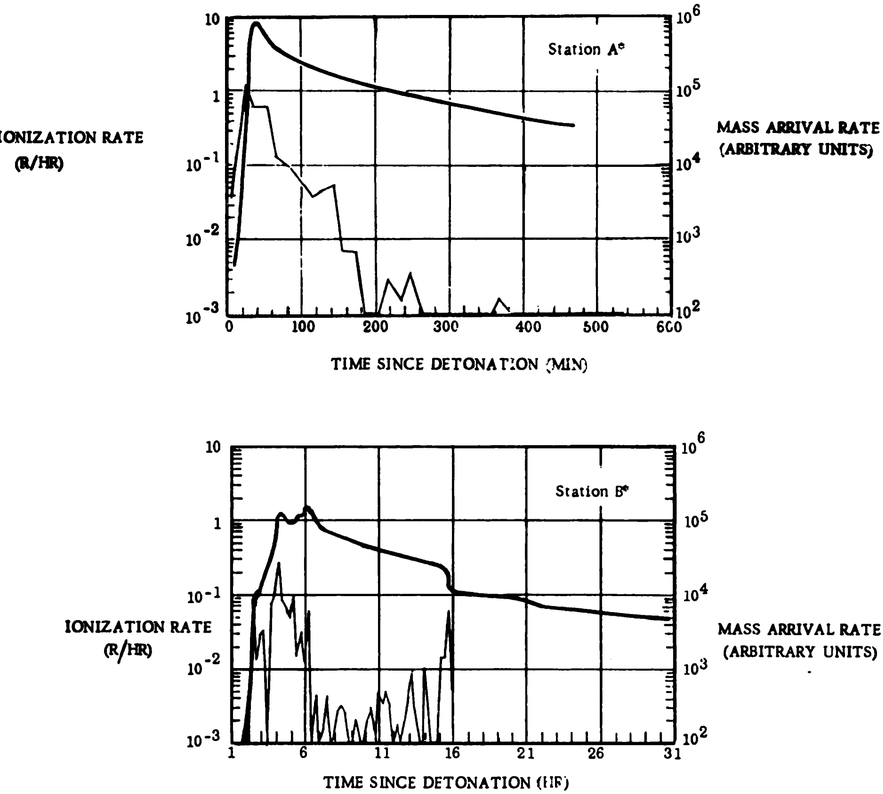


FIGURE 10 WATER SURFACE BURST FALLOUT RATE OF ARRIVAL

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TABLE 6

PHYSICAL PROPERTIES OF WATER SURFACE BURST FALLOUT

Properties of Particles	Station A* ($\sim$7 mi downwind)	Station B* ($\sim$22 mi downwind)
General Description	Salt slurry droplet containing insoluble solids.	
Range of Diameters	$\sim$ 0.08 to 0.30 millimeter	
Predominant Size	$\sim$ 0.275 millimeter in diameter	$\sim$ 0.225 millimeter in diameter
Size Range of Insoluble Solids	0.03 millimeter in diameter to sub-microscopic.	
Color	Droplets translucent white, solids amber.	
Shape	Droplets spherical, solids agglomerated spherical.	
Specific Gravity	$\sim$ 1.3 gm/cm^3	
Distribution of Radioactivity	Approximately equal partition between soluble and insoluble components.	
Relation of Radioactivity to Size	$A \propto$ NaCl Wt.	

*Contours not shown; similar to Fig. 7a.

TABLE 7

CHEMICAL AND RADIOCHEMICAL PROPERTIES OF WATER SURFACE BURST FALLOUT

Properties	Station A* (∽7 mi downwind)	Station B* (∽22 mi downwind)
Principal Components	Sodium chloride, water.	
Relative Solubility	About 50% of radioactivity soluble in water.	
Solid/Liquid Wt. Ratio	∽1	
Principal Fission		
Gamma Emitters		
1/2-1 hr	Cs, Nb, Te	
6-7 hr	I, Y, Kr, Sr, Nb	
1 yr	Nb, Zr, Pr, Ba	
Beta Emitter	Sr^{90}	
Principal Induced		
Gamma Emitters		
1/2-1 hr	U^{239}, Np^{239}, Na^{24}, Cl^{38}	
6-7 hr	Np^{239}, Na^{24}, U^{237}	
1 yr	Co^{60}, Mn^{54}, Co^{58}	
Beta Emitter	C^{14}	
Relative Fractionation (Mo^{99})		
Important Products	Sr^{90}, Cs^{137}	
% Depletion	10-30 35-50	
Initial Partition-% in Local Fallout		
% Total Fissions (Mo^{99})	65-75	
% Important Products	Sr^{90}, Cs^{137}	
	50-60 25-55	

* Contours not shown; similar to Fig. 7a.

TABLE 8

RADIATION CHARACTERISTICS OF WATER SURFACE BURST FALLOUT

Characteristics	Station A* (∽7 mi downwind)	Station B* (∽22 mi downwind)
γ Ionization Decay Rate	See Fig. 11	
Average γ Energy		
1 hr	∽1.0 mev	
2 hr	0.95	
1/2 day	0.60	
1 day	0.40	
1 week	0.35	
1 mo	0.65	
2 mo	0.65	
1 yr	0.55	

* Contours not shown; similar to Fig. 7a.

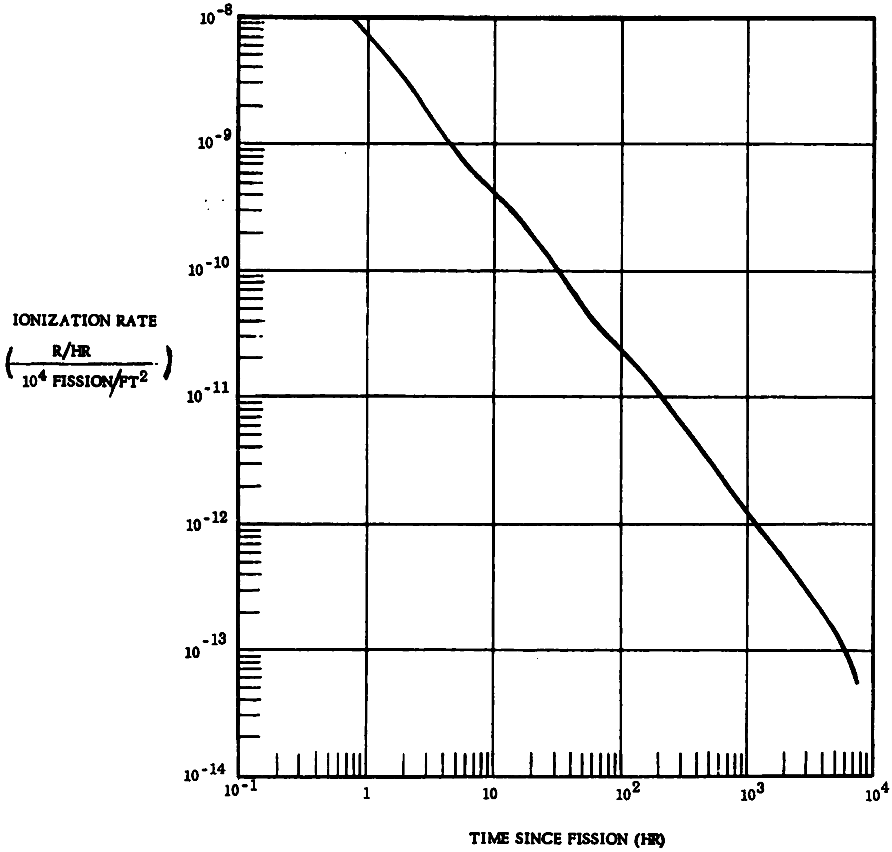

FIGURE 11 WATER SURFACE BURST RADIOACTIVE DECAY RATE

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Basic Properties and Effects of Fallout

Composition of Debris

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Summary

The nature of the fallout is described for two basic detonation conditions:

(1) a ~5 MT burst on the surface of silicate sand in an industrial area,

(2) a ~5 MT burst on the surface of a deep ocean harbor among a group of ships.

These conditions were selected for several reasons: they represent likely conditions for the given attack pattern, they will produce widely different kinds of fallout, and they represent conditions to which existing data most nearly apply. There have been only kiloton bursts on silicate sand, however -- none in the megaton range.

Basic processes of particle formation and contamination are discussed and it is shown how these processes can lead to local fallout which is depleted in such radioactive products as Sr^{90} and Cs^{137}, which are decay products of rare gases. The initial partition of these products for land and water surface bursts is estimated. It is also emphasized that fusion weapons,

because of their increased neutron output, can produce large quantities of radioactive fallout.

Typical fallout situations at near and distant stations are described and the arrival characteristics, the physical, chemical and radiochemical properties, and the radiation characteristics of the contaminated material for the two conditions chosen are estimated. It is shown that the average energy of the gamma radiation varies significantly over the time considered, and that the radioactive decay rate deviates considerably from the average rate usually estimated ($\propto t^{-1.2}$) -- being slower at early times and faster at later times. Isodose rate contours for a megaton burst are given and it is shown that, because of varying high-level winds, they are highly irregular and contain isolated "hot spots" at considerable distances from ground zero. The point is made that widely different radiation doses could be received in regions not too far apart in a real fallout area.

In conclusion the distinction is drawn between contaminated particles and the radiations from contaminated particles. This is then used to emphasize the difference between external and internal radiation hazards from fallout.

Dr. TRIFFET. However, it is my intention to speak informally from a few notes in order to make it a little easier to ask questions.

The subjects that I plan to cover are not quite as familiar concepts as some we have already heard, so if you have questions, please do not hesitate to ask them.

I also want to mention that in the outline of the material that I am to cover, it is mentioned that I will speak of the products of fission and fusion and cover deviations from theory. I will, in fact, do both of these things, but I will do them in the course of the discussion in order to give a more integrated presentation.

There are, however, three important deviations from theory which I would like to emphasize. The first of these has to do with the fractionation of nuclides. By this is meant an unequal partition of the nuclides produced by the detonation between the worldwide, or distant, fallout and the local fallout.

The second thing will be deviations from the average rate of decay, which is ordinarily quoted as $t^{-1.2}$. This is an important point for civil defense, because our data show that the decay rate is actually slower at earlier times and later becomes much faster.

The third point I would like to make has to do with deviations from the smooth, cigar-shaped contours that are ordinarily drawn. All of these concepts are quoted at present in the Effects of Nuclear Weapons, and our data show that they may be seriously in error. This is the reason I would like to try to bring them out especially clearly.

Representative HOLIFIELD. You said that the data in the nuclear weapons handbooks which were published 3 years ago may be seriously in error?

Dr. TRIFFET. Yes, sir.

Representative HOLIFIELD. Will you please, then, as you go along show where they may be in error according to present information?

Dr. TRIFFET. Yes, I will emphasize this in the discussion.

I will try to describe for you the fallout which would occur under two basic conditions. These conditions[1] are: the detonation of about a 5 megaton, 50 percent fission-50 percent fusion, weapon on the surface of silicate sand in an industrial area (condition 1), and the detonation of a similar weapon on the surface of a deep harbor near a group of ships (condition 2).

There are several reasons why I have selected these two conditions as opposed to many other possibilities. The first is that they are likely conditions under the attack pattern which has been prescribed. If you will look more carefully at the attack pattern, you will see that many of the detonations are clustered around the seacoast, and it is quite likely that a bomb could hit either in deep water offshore as a near-miss or on a sandy or clay-like soil in or near the city. The second reason that I have chosen these two conditions is because we know from experience that they produce widely different types of fallout. The fallout in this case is a slurry droplet.

Representative HOLIFIELD. When you say "this case," please identify it, so that the written record will show what you are pointing at.

Dr. TRIFFET. In condition 2, the detonation on the surface of a deep harbor, the fallout will consist of slurry particles—a little water and

[1] Conditions 1, 2, and 3 are contained in fig. 1, p. 62.

a lot of salt. In condition 1 they will consist largely of solid particles and consequently be quite different.

It is not, perhaps, the most probable detonation condition which is shown in condition 2. It appears equally likely that the most probable condition may be that indicated by No. 3, which is in a shallow harbor. The assumption is made implicitly here that the properties of the fall-out for condition 3 will probably lie somewhere in between the two types indicated for conditions 1 and 2.

The third reason why these were selected as detonation conditions is that they are those conditions to which our existing data most nearly apply. I want to hasten to add, however, that we have no megaton range detonations on a silicate sand soil. Instead, all of the megaton detonations have been on coral sand in the Eniwetok Proving Grounds. All of the kiloton detonations have occurred in Nevada. So there is a large region where we have to extrapolate the kind of particles which might be produced.

I also want to point out that I have carefully put steel in both of these detonations. The reason for this is because there has, in fact, always been steel present in the tests conducted by this country. There is reason to believe, as will appear later in some of my other testimony, that metals in general, and iron in particular, may play a critical role in fallout formation. So it is important to realize that I have indicated these, not only because they are likely conditions, but also because they are the conditions we can best understand.

I also want to say at this point that, since we really do not know exactly what a megaton burst would do on a silicate sand soil, it would be possible for me to speak in generalities from this point forward. Instead of doing that, I have chosen to do my best to give some definite numbers. I do this to avoid vagueness, but I hope it will be understood that we do not have any direct data for this case, and that I am extrapolating from known conditions.

There is one point I did not mention. The height of the burst is also a primary variable in the formation of fallout. In the cases we have selected here, featuring land surface bursts, both local and worldwide fallout would appear to be maximized. If you go higher in the air for the burst, then probably you maximize worldwide fall-out alone, as was brought out this morning. On the other hand, if you go deep enough underground, you maximize only local fallout. So these again are intermediate conditions.

I had planned to tell you a little more about basic nuclear explosion processes than I am going to now, because Dr. Shelton brought this out clearly in his discussion. There are, however, two or three important points I would like to reemphasize.

One is that in both fission and fusion part of the mass of the system, that is, of the atoms involved, is converted to energy. This energy has to be dissipated, and it is in the process of dissipating the energy that we get into all the problems. Part of the energy is dissipated by the motion of the product atoms, as indicated here in figure 2 (p. 66) for fission. Part of the energy is dissipated by the emission of heat rays and light rays by the excited atoms. Either those which have been fissioned or, as indicated in the lower line, those which have been fused. The heat and light ultimately come off as direct radia-

tion from the fireball and constitute somewhere around 35 percent of the total energy.

If there is only one atom fissioning, it is possible to dissipate the energy in the surrounding medium with no problems. If there are a great many, then the energy cannot be dissipated quickly enough and shock wave builds up. This shock wave carriers off about 50 percent of the energy. The remaining 15 percent goes to nuclear radiations, and although ideas do vary about the partition between shock and heat and light within the 85 percent, the 15 percent remains fairly constant. About 5 percent of the total energy of the bomb is emitted as nuclear radiation initially. This leaves about 10 percent for residual radiation, which appears in the form of radiation from the atoms formed by fission, and it is this percent which we are mostly concerned with in the fallout process.

I do want to make one other point. There are over 40 ways in which a uranium atom can split in fission, and you end up with 90 or more primary radiation products. These fission products must then decay and emit nuclear radiations, which constitute part of the problem we are concerned with. However, notice too that in the case of fusion the final process leads to the production of a great many neutrons, probably more than in the case of fission. These neutrons are capable of inducing activities in environmental and bomb materials which are one of the primary sources of the radioactivity produced by fusion weapons.

I think this would be a good time to emphasize that fusion weapons are capable of inducing radioactivity in bomb and environmental materials. Fusion weapons sometimes contain uranium. If they do, the neutrons of fusion can fission or induce radioactivity in the uranium. In addition to this, fusion bombs usually require fission triggers. What this really means, particularly in our case where we have a 50-percent fission, 50-percent fusion weapon, is that a fusion weapon is capable of producing large amounts of radioactivity. In this sense a fusion weapon can be referred to as a clean bomb only in the sense that gray could be referred to as light relative to black. A fusion weapon may only be considered clean relative to a pure fission weapon.

Representative HOLIFIELD. On the point of induced radioactivity, I think it might be well at this time to explain in lay terms what you mean by that. Let us go to the Mike shot in the Pacific where a cavity was created in the island about 165 feet deep in the center and almost a mile across, as I remember. My memory seems to revert to the figure of 400 million tons of coral rock scooped out of that location and reduced to ash which had induced radioactivity, and which therefore became particles of radioactivity by inducement rather than origination.

Dr. TRIFFET. It is highly likely that the activity that was induced was really the result of neutrons interacting with ocean water much more than with coral. The significant radioactivities in this case are sodium 24 and chlorine 38. Both of these are from components of sea water. That is, they are formed by neutrons interacting with the atoms of sea water.

Representative HOLIFIELD. Then in the case of a fission-fusion weapon of a megaton value being dropped into any of our Atlantic or

Pacific harbors, we would be faced with an accretion of radioactive particles because of the sodium in the salt water?

Dr. TRIFFET. That is correct. However, sodium also appears in soil to some extent. There are other induced radioactive products, too. I will mention some of these later.

Representative HOLIFIELD. Is there any way that we can compare the total amount of radioactivity induced by a 1-megaton bomb which has been exploded on dry ground and one which has been exploded in shallow water of a harbor, such as Los Angeles or Boston or some other fairly shallow harbor?

Dr. TRIFFET. The answer to this is not available at the present time. There have not been any detonations enough like the second condition that you describe, to allow us to even reasonably extrapolate. The best we can do is to establish the two limits.

I show figure 3 (p. 68) in passing simply to emphasize what is meant by fission products. If you have an assembly of atoms which are fissioned by the chain reaction resulting from the introduction of neutrons at the right energy, each atom divides in two, but it can do so in a number of different ways. The result is many different radioactive products. These are indicated on the curve. It is a schematic indication which shows simply the percentage of each different kind of atom that would result from the fission of a large number of atoms of uranium 235.

The way atoms of different types are ordinarily indicated is by mass number. This can be thought of as the weight of the nucleus. Strontium 90 is, therefore, identified by its particular mass number, molybdenum 99 by another, and cesium 137 by another. In fact, there are many different atoms with different mass numbers, as indicated along the bottom of the figure. You can see by looking along the edge of the figure the percentages of these that would be produced. Separate from this are induced products. These are products like sodium 24 which are induced by neutron interaction with the environmental material or bomb material.

This is part of the reason why I wanted to show you the early division of energy.

Representative HOLIFIELD. May I ask you a question at this point? Would you comment on the effect on health of molybdenum 99?

Dr. TRIFFET. Yes. Molybdenum 99 is not a health hazard. It is used as a reference nuclide. If you want to determine the percentage of the bomb which appears in some sample, you must have a reference to base the calculation on. Molybdenum 99 is used for this reason because it is thought not to fractionate. There are some things wrong with this idea though.

I ended the discussion of figure 2 (p. 66) with the idea that there is a fireball created. Figure 4 (p. 71) takes over at that point. The object of the figure is to show how fallout particles are formed.

The first sketch, designated as (a), indicates the fireball when the temperature is very high—probably several hundreds of thousands of degrees centigrade. At this time all of the fission products, induced products, bomb and environmental materials are very hot; because of the great thermal agitation, of course, they stay separate.

The next stage occurs when the fireball cools and a lower temperature is reached. The fission and fusion products are decaying all

the time, but now they also begin condensing. The bomb and environmental materials also begin condensing. These condense in order of their boiling points. There is, of course, some speculation in what I am saying now. It is not all cut and dried by any manner of means. However, most of the things are not too questionable. It would be hard to sort these out though, and I will try to give a unified picture here.

At any rate, the materials in the fireball tend to condense in the order of their boiling points. This means that metals, which have high boiling points, will tend to condense out first, while things which have low boiling points will tend to remain in a gaseous phase until much later. This is a critical point which it is important to understand.

After the bomb and envronmental materials begin to condense out, they form small particles—little iron spheres in some cases. The fission products then may deposit directly on these, since there are very few fission products and probably a lot of iron and other particles. They could condense on themselves too, though.

A later phase, after the fireball has cooled even further, is where late environmental materials (soil or water) are drawn up into the early cloud. Notice what can happen then. The fission porducts and induced activities, which is what we are concerned with after all, can either deposit directly on the soil particles, or these small spheres which were formed earlier can deposit on the soil particles. This means that you can get various distributions of the activity on the particle. Of course, in the beginning, the environmental materials are melted when they are taken in. The temperature is very high. Then the temperature drops lower and finally you reach the point where the particles simply melt. Eventually, I suppose, the temperature drops even lower and they do not even melt. It is prior to this, however, when the primary activity is deposited on the particle.

The next thing that happens is that the larger particles begin to fall out. These larger particles naturally contain mostly the nongaseous radioactive products; whereas the small particles and the gaseous radioactive products (which will eventually decay and be deposited on the smaller particles) remain for longer times in the cloud. This process is known as fractionation. I want to be very sure I have gotten the idea across, because it is quite fundamental to understanding some other important points—the simple process of the large particles falling out before the gaseous materials can condense on them by decay.

As you can see, this process could well mean that the worldwide fallout is enriched in those products which are gaseous at early times. Two of these are strontium 90 and cesium 137. It follows from this that strontium 90 and cesium 137 may well be fractionated in the wrong direction. That is, they may be relatively richer in worldwide fallout. This is what our data show.

I wanted to point out in passing what the fallout particles look like for the two conditions. In the case of the land surface burst, the particles look generally like those shown on the left in the illustration. You will notice that there may be iron spheres inside the particle. There may also be fission products and induced products which are not on any metal spheres inside the particle, or all of the activity may be on the outside. I want to say that we have only

observed particles where the small iron spheres were all on the outside in the case of one Pacific event.

You will remember that I said we have not had a megaton burst on silicate sand. We have reason to think, however, that the particles in this case would look like the left-hand particle in the illustration.

Senator JACKSON. How well can you extrapolate from the information we have received from the actual tests to apply to the various environmental situations around the country?

Dr. TRIFFET. There are several things which have to be said in connection with that. Particle size distribution is one of the big problems. Silicate sand has a certain particle size distribution and this influences the fallout. Clay is also primarily composed of silicates, but it has a different particle size distribution. I am not prepared to state how much this influences the fallout, but we think it does to some extent. The only thing I can say in answer to your question is that in return for trying to give definite numbers, I hope you will not ask me to generalize too much on either side of the two conditions selected.

Senator JACKSON. I appreciate your wanting to be scientific and accurate about it.

Representative HOLIFIELD. One of the problems we have in holding hearings such as this is that the average lay public wants everything boiled down into crystal clear black and white patterns. One of the things that these hearings will show will be that we just can't do that under the present state of knowledge. Also, some of this may be quite technical to the general lay public as it is to some of the members of the committee, including myself, but it is necessary to put this knowledge on the record so that those who do read with a critical eye, and those with particular knowledge in the sciences may realize that we have tried to do an honest job and earnest job, in putting as much material on the record as we can in the time that is allotted us.

Dr. TRIFFET. There is one thing I could say about the use of the Nevada-type particle, extrapolated to the megaton condition. Particle size is a critical factor because it determines the rate at which the particle falls. It is also related closely to the total activity, that is, activity increases with particle size. So it is quite possible that changing the particle size distribution would mean that the fallout would arrive earlier or later at a given point. It might also be more or less radioactive. That is why I am hedging on this point. The only possible answer to this is further theoretical work and small-scale tests, or something of the kind. It is an important point.

Representative HOLIFIELD. Will you proceed, sir?

Dr. TRIFFET. I thought I would give you some figures now. I have indicated that strontium 90 and cesium 137 might be fractionated under both conditions, but certainly worse in the case of a land surface burst. The best figures I can quote are the result of recent measurements. You will notice that they have a fairly wide spread, but I think they are worth putting on the board anyhow.

In the case of a water surface burst molybdenum 99, which is indicative of the total activity, shows about 65 to 75 percent deposition in the local fallout. Strontium 90 on the other hand, because of the fractionation I have been describing, shows only 50 to 60 percent deposition in the local fallout and cesium 137, 25 to 55 percent. These

are slightly fractionated, but not as badly as in the other case. It appears that 90 to 95 percent of the molybdenum 99 may be deposited locally for the land surface burst, while only 45 to 70 percent of the strontium 90 and 10 to 30 percent of the cesium 137 are deposited locally.

It might be mentioned in passing that what this really means in the case of the land surface burst is that the total activity will be higher in the local fallout, so that the gamma-ray hazard will be relatively greater. On the other hand, the worldwide fallout may be enriched in strontium 90 and cesium 137, which constitute two of the most serious long-range hazards.

I would like to try to describe for you now the fallout a person would experience if he were standing just outside the range of shock and thermal damage from a detonation of this kind. I have designated this location as the near station.

The first thing that would happen is that he would receive an intial radiation dose, which we usually refer to as transient radiation, from the falling particles. It is important to note that this can be received at a point even though the particles are blown by and actually not deposited there.

Then after a short time—perhaps 15 to 30 minutes—he would become aware of a rain or large particles falling all around him. These particles would range from half a millimeter to several millimeters in size and would probably be clearly visible. They would vary from light green to yellow in color on the light side and from brown to black on the dark side. I have an exhibit to show you which is representative of the distribution of particle sizes that might be present at such a location. It consist of sand (with no radioactivity present) representing 25 gram per square foot fallout—the amount of material associated with roughly 1,000 r./hr. I think you can see that it would be clearly visible.

You can also see that it would be visible on various surfaces. There may be some conditions when it would not be visible, of course, where the background was wrong.

On the other hand, this sample represents about 0.025 gram per square foot, and the dosage associated with this amount of material would be about 1 r./hr. It would be very difficult indeed to see this. Perhaps you can just see a light mist falling, but nothing is visible on the tray surfaces. That was quite a jump from 1,000 to 1 r./hr., but at least it is representative of the two situations I am describing.

After these particles began to arrive at the near station, where our observer is located, the dose rate would begin to build up very rapidly. The concentration of the material passing through the air near him would also build up rapidly.

I have attempted to show this in figure 5(a) (p. 76). You will notice that the dose rate is shown on the lefthand side, for the upper curve. The mass arrival rate in grams per square foot per hour is shown on the right side for the lower curve.

Notice that in the interval between about 20 minutes and 2 hours the mass of material arriving first increases mightily, and then stops. The dose rate goes up rapidly, reaches a peak, and then begins to decay. If our observer were at a distant station, instead, he would either see nothing or a disperse cloud of fine particles settling very

slowly. The conditions at the near station might be somewhat like a mild desert sandstorm. At the distant station he might not see the particles at all, and the dose rate would be much lower. Figure 5(b) (p. 76) shows what would happen there. Notice that buildup takes about 20 hours as opposed to less than an hour in the other case. The mass arrival rate remains very low all the time.

It is also true that at these early times the average energy of the gamma radiation would be higher, meaning that the radiation would be relatively more penetrating. At later times the average energy would be lower, and relatively less penetrating. This difference is not large, but it should be mentioned.

I should also mention that the particles at the near station would be large and easy to remove from most surfaces. You could brush them off, and would not run much danger of inhaling them. Just the opposite would be true at the distant station.

Of course, after the material ceased to arrive radioactive decay would begin to predominate. This decay rate is very important, as you have seen from much of the previous testimony. Our data show that the irregular curve in figure 6 (p. 77) would be the actual decay rate, or more nearly the actual decay rate, in the case of a weapon such as the one chosen for this study—namely, a 50 percent fission–50 percent fusion weapon, with induced activities present.

You will notice that at early times, the dose rate is higher than that which is given by the $t^{-1.2}$ approximation. This is due largely to the presence of induced products. At later times, however, the dose rate is much lower. If you were to follow the curve further, you would find that the lower loop begins to come up a little eventually. Nevertheless, at times somewhat less than 1 year it begins to drop precipitously; consequently, the $t^{-1.2}$ rule greatly overestimates the dose rate.

Representative HOSMER. You are speaking of the total radioactive products produced by the detonation?

Dr. TRIFFET. I am speaking of the roentgen dose rate. These are not the same thing. A lot of the confusion which enters into the estimates one sees comes from this very point. If there are a large number of radioactive atoms disintegrating, these disintegrate at a certain rate, and the total amount has a certain half life. As each atom disintegrates, however, it emits a beta particle and may or may not emit one, or more, gamma rays. It is the gamma rays which are primarily responsible for the kind of ionization we are interested in. Consequently, the ionization rate may not be linearly related to the disintegration rate. Perhaps I have made enough of this curve, but I did want to mention in passing that fractionation can operate either way on radioactive decay—it could operate to lower the early rate, for example, or increase the late rate. That is, if the normal mixture of fission products varies, changing the nuclide ratios, the r./hr. curve may either straighten out or become more bumpy. The end result depends entirely on the nature of the fractionation—although the latter has been observed to straighten the curve out to some extent, at least, at early times.

After the fallout has ceased at the near station and the distant station, what would the overall contaminated area look like? I have attempted to show this by reproducing some dose rate contours from a

real event. Obviously it is a Pacific test, because it is in the megaton range. The much smaller set of contours on the right represents a Nevada test.

I have also attempted to show the near station and the distant station which I have been discussing in terms of fallout properties. These cannot be interpreted too literally but they are at least indicative.

Representative HOLIFIELD. Is the point you are making here that the actual contour, in the place of being elongated and more like the shape of a banana, let us say, is wider and more an irregular round type of shape as you have on the left?

Dr. TRIFFET. There are in fact three points I want to make and the first one is that. The contours from the large burst are very irregular compared with those from the small burst. This is because the megaton burst produces a cloud which rises into the high level winds, and these may vary in direction. When they vary in direction the kind of a pattern indicated as (a) may result.

Representative HOLIFIELD. Will you trace the center roentgen level there out to the different contours?

Dr. TRIFFET. That leads directly to the second point I want to make. Near ground zero there is a 1,000 r./hr. at 1 hour contour with a 500 r./hr. contour adjacent to it. Next there are contours which, in general, step down to 250, 100, 50, and 25 r./hr.

Representative HOLIFIELD. That is upwind.

Dr. TRIFFET. Yes, sir. Notice, however, that downwind, because of the effect of varying winds at higher levels, there is a 2,500 r./hr. region perhaps 40 nautical miles from ground zero. Another 1,000 r./hr. area appears further out still.

Representative HOLIFIELD. According to that, your high areas of intensity may be some distance from point zero.

Dr. TRIFFET. That is correct.

Representative HOLIFIELD. What would this do to the maps we saw this morning? If this type of contour had been used would it not have changed the readings of the maps we had before us this morning?

Dr. TRIFFET. Yes, it would. What these two things I have brought out mean, is that, inside the fallout area from a real megaton burst, it is altogether possible to receive widely different radiation doses at points which are not too far removed, from one another. Consider the near station, for example. Within about 10 miles of there, one could have received 2,500 r./hr. while within about 20 miles of the same spot one could have received less than 25 r./hr.

I do not want to overemphasize this situation though for the following reason. Notice the contours of the 1 kiloton burst. The cloud did not get into the high-level winds in this case; consequently, it is easy to see how the contours could be generalized into a cigar shape.

Representative HOLIFIELD. Isn't it true that it would be in a cigar shape if it did not go into the stratosphere, and if it were below the troposphere?

Dr. TRIFFET. I cannot say definitely. These contours are somewhat irregular, and they would generally be, I think.

Representative HOLIFIELD. We understand that these are idealized to a certain extent. They are not absolutely accurate. It is an attempt to draw the pattern of downwind radioactivity. Any bomb that

was low enough in yield to not puncture the troposphere would be inclined to have more of a regular downwind pattern than one that went above 60,000 feet. Is that not true?

Dr. TRIFFET. Yes. There is another factor that should be brought out, too, and that is that the winds over the Eniwetok Proving Grounds have a tendency to vary more than the winds over the United States—the high-level winds, that is. This means that it might be possible to get a less irregular pattern in the United States—although there is a lot of evidence for removed hot spots and some irregularity in any case.

Representative HOLIFIELD. This irregular pattern does not necessarily mean that your spread of radioactive intensity with a multiple weapon attack such as we have envisaged here, would not have an intense radiation activity which might approximate what was given us this morning?

Dr. TRIFFET. No, it does not mean that, because of the possibility of getting overlapping patterns from different weapons.

Representative HOLIFIELD. You would actually get more overlapping in a pattern of this type which would be expected from the megaton and up weapon than you would from the smaller weapons.

Dr. TRIFFET. I am not sure of that, and would rather not comment on it.

Representative HOSMER. The matter of fact is that a certain wind condition would produce the exact patterns shown on the maps this morning.

Dr. TRIFFET. Yes, very nearly.

Representative HOSMER. But nobody can speculate exactly what the wind conditions are and as a consequence nobody can predict at any time with any degree of accuracy just where the hotspots are going to be, but you can in general attain an order of magnitude idea of what is going to happen over a particular piece of real estate.

Dr. TRIFFET. Yes, that is correct.

Representative HOLIFIELD. If my colleague will change the words "any degree" to "some degree" of accuracy, I will go along with him on that.

Representative HOSMER. I would be happy to accommodate you.

Dr. TRIFFET. Dr. Machta did make the point that the patterns might well be irregular. They have been idealized and this must, of course, be recognized. If there are not further questions, I will go on.

Representative HOSMER. While we are about this, you mentioned fractionation again in discussing this phenomenon here. By your reference to that twice, is there something about it that you could use to actually control fallout to the extent of making more early fallout?

Dr. TRIFFET. This may be possible, and studies are underway along these lines. However, I would rather not discuss them in detail now.

Representative HOLIFIELD. You may proceed.

Dr. TRIFFET. I would like in conclusion to mention one or two things which are often misunderstood about the radioactivity as-

sociated with fallout. These are the following. It should be clear from what I have said that contaminated particles and radioactivity from contaminated particles are two different things. The particles are contaminated in the sense that they are carrying radioactive atoms which are decaying and emitting nuclear radiations. The best analogy, I think, is to compare a particle with a light bulb, and the radiations with the light. The bulb is a substantial physical object, as is a fallout particle. The radiation, on the other hand, is a concentration of energy, like the light. As you move farther away from a lighted bulb, you get less light. This is true of the nuclear radiations from fallout particles, too. Some are very short range radiations, called alpha and beta particles. Gamma rays are not like this, however; they are long-range radiations which penetrate large distances.

Perhaps this will make it clear that internal and external radiation hazards are also two different things. If one is exposed to a contaminated particle which is a long distance away, then only an external radiation hazard from the gamma rays exists. On the other hand, if one has such a particle on his skin, there is a contact hazard from the short-range beta radiation. Even worse, if the particle is swallowed or inhaled an internal hazard is created from all of the radiations the particle is emitting. There are some radioactive products which do not emit gamma rays at all, and therefore pose practically no external radiation hazard. It makes absolutely no sense to compute an external radiation dose for these nuclides; but they may represent a serious internal hazard, nevertheless. Strontium 90, and carbon 14 are two of the principal culprits in this case.

Representative HOLIFIELD. This is because these nuclides, as you say, do not emit long-range energy particles where if they are taken internally and become a part of the bone or muscle structure, then their radiation is for a limited distance in their environment within a person.

Dr. TRIFFET. That is correct. Radiations always damage the body in the same way—or damaging the individual cells through ionization. It is mostly a question of whether the radiation can get to the cells or not. For the gamma rays the source may be a long way off; for beta particles it has to be close.

I think this concludes my remarks, but I will be glad to answer any questions.

Representative HOLIFIELD. Thank you very much. Are there any questions? If not, then we thank you very much for your presentation. I am sure the scientific material you have given us will be very valuable.

Before Dr. Machta begins, I have a paper by Dr. Knapp, of the AEC, for insertion in the record at this point.

A Review of Information on the Gamma Energy Radiation Rate from Fission Products, and its Significance For Studies of Radioactive Fallout

By

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SUMMARY

Recent independent studies by the Naval Radiological Defense Laboratory and by scientists and engineers concerned with the shielding of nuclear reactors indicate that the gamma energy radiation rate from fission products of thermal neutron fission of U-235 for times between several minutes and 100 years differs significantly from the value predicted by the $t^{-1.2}$ decay law and other information given in the official government publication "The Effects of Nuclear Weapons." The difference occurs both in the absolute level of the energy release rate from a given quantity of fission products at some standard time following fission (usually taken as 1 hour), and in the relative variation of this rate with time.

Based on "The Effects of Nuclear Weapons," the gamma radiation rate is computed to be $0.58t^{-1.2}$ Mev/sec/10^4 fissions (t in hours). At 1 hour this rate is lower than that computed by the NRDL by a factor of 2.3; at 2 years it is greater by a factor of 7. The differences at other times are shown in Table 1. A release rate of $0.87t^{-1.2}$ Mev/sec/10^4 fissions approximates the NRDL computations to within 25% for times between 6 hours and 3 months following fission, but such a rate is uniformly 50% greater than that predicted by the rules given in "The Effects of Nuclear Weapons."

Changes in the gamma energy release rate associated with a given quantity of fission products may be reflected in estimates of the fraction of the fission products created in a surface burst nuclear explosion which fall to earth as part of the local fallout, which in turn affects estimates of the fraction contained in the global fallout. This is because the fraction of the fission products contained in the local fallout has often been estimated by computing the areas associated with each dose rate level measured in roentgens/hour at 1 hour, and deducing from this information the area distributions and total quantities of fission products contained in the local fallout on the basis of the data given in "The Effects of Nuclear Weapons." Since the open field gamma dose rate in roentgens/hour from the radioactivity in fallout is very nearly proportional to the gamma energy release rate per unit area, a change in the gamma energy radiation rate associated with a given quantity of

fission products will be reflected in a change in the quantity of fission products per unit area on the ground associated with a given measured dose rate level in roentgens/hour. The differences between the NRDL and "Effects of Nuclear Weapons" estimates of the roentgen dose rate associated with a fission product contamination level of 1 kiloton per square mile are shown in Table 2. 1/

Another situation in which the differences between the NRDL computations and the information given in "The Effects of Nuclear Weapons" are of particular interest arises in comparisons of the relative importance of fission products and induced activities for weapons of reduced fission yield.

A review of available information on the energy release rate of fission products indicates that the NRDL results provide a more accurate representation of the gamma energy release rate of the fission products from the thermal fission of U-235 than does the information given in "The Effects of Nuclear Weapons," although this has not been confirmed by direct measurements for all time periods of interest. However, even if the energy release rates computed on the basis of the latest nuclear data are accurate for the thermal fission of U-235, there are three ways in which differences might arise between these results and the gamma energy release rate of fission products in weapons debris:

1. Fissions in weapons are caused by neutrons with much higher energies than thermal neutrons, and the relative yields of the various fission products change as the energy of the neutrons causing fission changes.

2. Pu-239 and U-238 are fissioned in many weapons, as well as U-235. In some high yield weapons a major fraction of the fissions is from U-238. There are known differences in the fission yields of the different fissionable materials.

1/ Estimated external gamma doses for most communities around the Nevada Test Site were based on measurements of the gamma dose at the communities and on film badge data from the inhabitants. In cases where direct measurements were not made, estimates were made by interpolating data from nearby locations with higher and lower levels of exposure.

3. There may be fractionation of isotopes in weapons debris which would cause the gamma energy release rate for the fission products found in the local fallout to differ at certain times following detonation from the release rate of the same number of fission products in the global fallout, and in both cases to differ from the release rate which would obtain if there were no fractionation--that is if all fission products attach themselves to fallout particles in the same proportions as they were created.

Another complexity is introduced into measurements of the gamma energy radiation from actual weapons debris by the many activities induced in weapons materials and elements in the earths crust by the neutrons released in the detonation. At the present time it is often not possible to give a satisfactory explanation as to the measured shape of the gamma dose rate curve or to give a very firm estimate of the distribution of the radioactivity generated between the local and global fallout.

DISCUSSION

It is very nearly true that the open field, external dose rate in roentgens/hour caused by the fission products in radioactive fallout is proportional to the gamma energy emission rate of the fission products. At present, most estimates of external gamma dose rates from the fission product fallout following an atomic or thermonuclear explosion are based on rules and information provided in "The Effects of Nuclear weapons."1/ Recent studies, however, indicate that the standard assumptions concerning gamma energy radiation rates from fission products may contain significant errors, particularly at times from 6 months to 3 years following detonation, but also in the first hours and days after the explosion.

The first object of this report is to summarize available information concerning the gamma photon energy radiation rate from fission products, and to indicate the specific assumptions which now seem most suited for fallout evaluations.

1/ Prepared by the Department of Defense, published by the AEC, June 1, 1957.

Determination of the gamma energy radiation rate from fission products may be broken down to two separate problems:

1. the relative variation in the energy release rate with time,

2. the absolute level of the energy release rate at some (standard) time from a fixed quantity of fission products.

The recent studies indicate significant differences with the official estimates on both counts.

The results given here will be expressed as Mev/sec/10^4 fissions. They can be translated to Mev/sec/kt fission or to kw/megawatt day of fission by the relations

$$1 \text{ Mev/sec/}10^4 \text{ fissions} = 1.34 \times 10^{19} \text{ Mev/sec/kt fission}$$
$$= 44.8 \text{ kw/megawatt day fission}$$

According to "The Effects of Nuclear Weapons":
"9.110 The mixture of radioisotopes constituting the fission products is so complex that a mathematical representation of the rate of decay in terms of individual half lives is impractical. However, it has been found experimentally that for the period from several minutes to 2 or 3 years [underlining added] after detonation the over-all rate of radioactive disintegrations (or rate of emission of radiations) by the fission products can be represented, to a fair degree of accuracy, by the relatively simple expression

$$(9.110.1) \qquad \text{Rate of Disintegration} = A_1\, t^{-1.2}$$

where t is the time after formation of the fission products, i.e. the time after the explosion, and A_1 is a constant factor, defined as the rate of disintegration at unit time, that is dependent upon the quantity of fission products. This equation can also be used, with appropriate values for A_1 to give the rate of emission either of gamma rays or of beta particles. A beta particle is liberated in each act of disintegrations, but gamma ray photons are produced in about one-half only of the fission product disintegrations, the fraction varying with time after the explosion.

"9.111 In considering the radiation dose (or dose rate) due to fission products, e.g. in fallout, the gamma rays, because of their long range and penetrating power, are

of greater significance than the beta particles, provided the radioactive material is not actually on the skin or within the body. Consequently the beta radiation can be neglected in estimating the variation with time of the dose rate from the residual nuclear radiation. If the fraction of fission product disintegration accompanied by gamma ray emission and the energy of the gamma ray photon remained essentially constant with time, the dose rate, e.g. roentgens/hour, would be directly related to the rate of emission of gamma rays. As mentioned in par. 9.34, this it not the case. The gamma rays in the early stages of fission product decay have, on the average, higher energies than in the later stages. However, for the periods of practical interest, commencing a few hours after the explosion, the mean energy of the gamma ray photons may be taken as essentially constant, at about 0.7 Mev.

"9.112 Although the fraction of gamma emitters varies with time, a fair approximation based on equation (9.110.1) is that, at any time t after the explosion

(9.112.1) Gamma radiation dose rate $= R_1 t^{-1.2}$
where R_1 is a constant.

"9.119 ...using equation (9.110.1) as the basis, the total gamma activities of all the fission products from a 1 megaton explosion have been calculated for various times after the detonation. The results are given in Table 9.119.

Table 9.119

Total Gamma Radiation Activity of Fission Products from a 1-Megaton Explosion

Time After Explosion	Activity (Megacuries)
1 hour	300,000
1 day	6,600
1 week	640
1 month	110
1 year	5.5

Radiation Dose Rates over Contaminated Surfaces

"9.120 If an area is uniformly contaminated with any radioactivity of known activity (in curies), it is possible to calculate the gamma-radiation dose rate at various heights above the surface, provided the average energy of the gamma ray photons is known. The results of such calculations, assuming a contamination density of 1 (gamma) megacuries per square mile, for gamma rays having energies of 0.7 Mev, 1.5 Mev, and 3.0 Mev respectively, are represented in Figure 9.120. The curve for 0.7 Mev is approximately applicable to a surface contaminated with fission products."

Note: The 0.7 curve shows a dose rate of 4.2 r/hr at 3 feet above the ground for a contamination level of 1 megacurie per square mile. The dose rate at this height for activities with other gamma photon energies vary approximately linearly with photon energies, so that 1 Mev photons would produce a dose rate of about 6 r/hr/megacuries/mi^2.

This information -- namely the $t^{-1.2}$ decay law, the 300 megacuries/kt at 1 hour following explosion, and the average photon energy per disintegration of .7 Mev -- together with the conversion factor 1 kt = 1.34 x 10^{23} fissions, enables one to compute a gamma energy release rate in Mev/sec/10^4 fissions for ready comparison with the more recent data. The results are shown in Table 1. The analytical representation is given by

$$\text{Mev/sec}/10^4 \text{ fission} = .58t^{-1.2} \quad \text{(t measured in hours)}$$

Recent studies by the Naval Radiological Defense Laboratory 1/ 2/ 3/ have mathematically synthesized the known facts concerning the formation and gamma decay of individual fission products to give a tabular representation of the energy emission rate as a function of time. These results are also shown in Table 1. It is seen from Table 1 that the NRDL results vary

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1/ USNRDL-TR-160 Proposed Decay Schemes for some Fission Product and Other Radionuclides CF Miller, 27 May 1957 Unclassified

2/ USNRDL-TR-187 Gamma Decay of Fission Products from the Low Neutron Fission of U-235. CF Miller, 11 July 1957 Unclassified

3/ USNRDL-TR-247 Ionization Rate and Photon Pulse Decay of Fission Products from the Slow Neutron Fission of U-235 CF Miller, P Loeb, 4 August 1958 Unclassified

appreciably both above and below the energy release rate based on the standard assumptions. For the first day, the NRDL predicted gamma energy release rate is roughly twice that given by "The Effects of Nuclear Weapons"; from 1 day to 1 month it is generally higher by a factor of about 50%; from 1 year to 10 years it is smaller by a factor of from 2 to 7. Such variations in predicted energy release rate for a given level of contamination would have a sufficiently great affect on the problems of passive defense against fallout, in assessing the significance of induced activities in weapons of reduced fission yield, and in estimating the fraction of fission activity contained in local and global fallout that it is considered worth examining the literature both for the basis of the estimates given in "The Effects of Nuclear Weapons" and for any subsequent independent evaluations of fission product gamma energy release rates.

Although no references are given in "The Effects of Nuclear Weapons," the rules and information given there are evidently based primarily on a paper prepared by Way and Wigner in 1945 and later published in Physical Review (Vol. 73, page 1318, June 1948). This thirteen page paper, called "The Rate of Decay of Fission Products" gives a theoretical derivation of the combined gamma and beta activity and energy radiation rates following fission by treating the fission products as "a sort of statistical assembly." The paper is based largely on a semiempirical formula for the energy differences between isobars as a function of mass number, and a rough empirical fifth power relation between the half lives and disintegration energies of fission products. The theoretical results are compared with a tabulation of experimental results obtained in the wartime atomic energy project, and it is concluded that the comparison is fairly good. Explicit numerical conclusions are given for the combined gamma and beta energy radiation rates from fission products and for beta activity for times between 10^{-2} seconds and 1000 days.

An explicit Way-Wigner representation of the gross gamma photon energy release rate is found in an abstract of a paper presented to the American Physical Society at Chicago in June 1946 (recorded on page 115 of Vol. 70 of the <u>Physical Review</u>, July 1946).

According to that abstract,

> "... the radioactivity which follows a number of fissions is thus made up of a number of individual activities of many periods and energies. The energy emitted per second per fission at time t after a fission is given by

$$\int_0^{\lambda_{max}} \lambda\, n(\lambda,t)\, E(\lambda)\, d\lambda$$

"where n (λ, t) is the number of nuclei of decay constant λ existing at time t after a fission. Evaluation of this expression gives, for times greater than one day, the result

$$\text{Mev/sec/fission} = 3.75t^{-1.2} + 96t^{-1.4}$$

where t is measured in seconds. For shorter times a curve is given. This is the total energy emitted, including that carried by neutrinos. Agreement with experimental results is fairly good. Handy rules of thumb giving correct values within a factor of two for times between 10 seconds and 100 days are

$$\beta + \gamma \; ; \; \text{Mev/sec/fission} = 2.66t^{-1.2}$$

$$\gamma \; ; \; \text{Mev/sec/fission} = 1.26t^{-1.2}$$

The total disintegration energy per fission turns out to be 22 ± 3 Mev."

The expression

$$\text{Mev/sec/fission} = 1.26t^{-1.2} \text{ (t in seconds)}$$

is equivalent to

$$\text{Mev/sec/}10^4 \text{ fissions} = .68t^{-1.2} \text{ (t in hours)},$$

so that the γ energy radiation rates predicted by this formula are uniformly 17% greater than those obtained from "The Effects of Nuclear Weapons."

In a summary of the wartime experimental results on the rate of gamma energy radiation from fission products given in their 1948 Physical Review paper, Way and Wigner list three experimental results which apply to time intervals of interest in fallout research. As given in Physical Review Vol. 73 page 1329, these results are

	Function of Time t after Fission (t in seconds)	When Valid	References
γ energy in Mev/fission/sec =	$.90t^{-1.20}$	10 sec - 1 day	S. Katcoff, B. Finkle, N. Elliot, J. Knight, N. Sugarman Metallurgical Laboratory CC - 1128, Dec. 11, 1943
	$4.2t^{-1.28}$	20 m - 3 days	L. Borst, Metallurgical Laboratory CL-697 VIII, C4
	$49.0t^{-1.41}$	50 - 100 days	

Expressed in Mev/sec/10^4 fissions for t measured in hours, these expressions become, respectively

1.	$.49t^{-1.2}$	10 sec - 1 day	(Sugarman et al.)
2.	$1.18t^{-1.28}$	20 m - 3 days	(Borst)
3.	$4.8t^{-1.41}$	50 - 100 days	(Borst)

The first of these formulae give a result uniformly lower than computations based on information from "The Effects of Nuclear Weapons." The second and third formulae (Borst) compare as follows:

Various Estimates of γ Mev/sec/10^4 fissions

	Time After Fission	
	1 hour	3 days
Borst (formula #2)	1.18	.0046
The Effects of Nuclear Weapons	.58	.0034
NRDL	1.31	.0042
	50 days	100 days
Borst (formula #3)	2.19×10^{-4}	$.82 \times 10^{-4}$
The Effects of Nuclear Weapons	1.17×10^{-4}	$.51 \times 10^{-4}$
NRDL	1.63×10^{-4}	$.6 \times 10^{-4}$

It is seen that the Borst experimental results for times between 1 hour and 3 days are in closer agreement with the NRDL computations than with information provided in "The Effects of Nuclear Weapons." For times between 50 and 100 days, the Borst experimental results are about as far above those of the NRDL as those derived from "The Effects of Nuclear Weapons" are below.

It should be noted the Borst results here tabulated are for a formula developed (presumably by Borst) to fit his experimental measurements, and not the measurements themselves. The reference to Borst's work given by Way and Wigner is not available here in AEC Headquarters. There is a comment in a paper by Perkins and King (discussed later) to the effect that their theoretical derivations are in close agreement with the results of Borst and that "the detailed points given by Borst

(to which the straight line is an approximation) follow the theoretical variations even more closely."

There have been several computations of gross energy release rates from fission products since the work of Way and Wigner in addition to those made by the NRDL. All are based on various compilations of the yields of the nuclides produced in fission and on their known or estimated decay schemes. One of the latest of these (in which many references to other work are given) is "Energy Release from the Decay of Fission Products," by J. F. Perkins and R. W. King published in the June 1958 edition of Nuclear Science and Engineering. According to the authors,

> "We have used the latest information on fission yields; in particular we used Pappa's modification of the equal charge displacement hypothesis which takes into account shell effects. We employ the same gamma energy groups as Moteff and Clark, and extend our calculations to shorter shut-down times by estimating spectra of those lived activities whose spectra have not been measured. Finally and most significantly, we have tried to get the best possible information on decay schemes. In this effort we have had access to the latest work (as of July 1957) of the Nuclear Data Group of the National Research Council."

The Perkins-King data for gross gamma energy radiation rates are given for times between 10^2 and 6×10^7 seconds so that it is possible to compare their results with those of the NRDL and "The Effects of Nuclear Weapons" over a period of from 1 hour to almost 2 years. The results are shown in Table 1.

A second paper entitled "The Activity of the Fission Products of U-235," dated October 31, 1958, by Knabe and Putnam and published by the Aircraft Nuclear Propulsion Division of General Electric extends the work of Perkins and King to both shorter and somewhat longer times after fission (1-10^8 seconds), with the rate at shorter times based on experimental work by Zobel and Love at Oak Ridge (ORNL-2081, p.95). These results are also shown in Table 1. The Knabe-Putnam results generally agree with those of the NRDL a little better than the Perkins-King results, but all three are in close agreement and differ significantly from the rates based on the $t^{-1.2}$ decay and other data from "The Effects of Nuclear Weapons."

In converting from gamma energy release rates per unit area to external gamma dose rates in roentgens per hour, there are some additional differences between the results obtained by the NRDL and those based on "The Effects of Nuclear Weapons" which will not be considered here (see USNRDL-TR-247). The dose rates and integrated doses from 1 hour obtained by each method are given in Table 2. These dose rates are those which would apply at 3 feet above a

smooth, infinite, plane uniformly contaminated to a level of 1 kiloton of fission products per square mile. In using them for most practical problems one must also take into account the reductions in dose rate which would take place due to partial shielding provided by terrain roughness and the gradual leaching of the radioactive particles down into the soil. The differences in roentgen dose rates shown in Table 2 are more pronounced than indicated by the differences in energy release rate shown in Table 1.

The significance of the gross gamma energy radiation rate from fission products for fallout analysis indicates the desirability of direct measurements of this quantity. Since fissions occurring in weapons are caused by neutrons with a broad range of energies and may occur in Pu-239 and U-238 as well as in U-235, the gamma radiation rate from fission products in weapons debris may deviate significantly from that due to the thermal fission of U-235. Consequently, next to measurements of the energy release rates from samples of weapons debris, it would be most useful to have results from the laboratory fission of U-235, Pu-239, and U-238 by neutrons with energies similar to those causing fission in typical weapons.

Although the open field roentgen dose rates will be approximately proportional only to the gamma energy radiation rate and not to the spectrum of the emitted energy, the spectrum is important in determining the effectiveness of different degrees and types of shielding, so that one is presumably also interested in the energy spectrum for each of the fissionable materials and for neutron energies representative of those causing fission in weapons. Only measurements on actual debris, however, can determine whether or not the energy emission rates and energy spectrums are altered by fractionation of isotopes and to what extent such alterations take place. It should be noted that measurements on actual debris are complicated by the presence of neutron induced activities from both weapon and earth materials. The exact contribution of these induced activities from air and surface bursts to the external roentgen dose rate are not now well understood, although it appears that they should not be neglected. Np-239, U-237, U-240, Na-24, and Mn-56 may account for a substantial fraction of the open field roentgen dose delivered by local fallout from some high yield weapons between 8 hours and 1 week.

TABLE 1

GAMMA ENERGY RADIATION RATE FROM FISSION PRODUCTS
(Mev/sec/10^{4} fissions)

Time	Release Rates: From Effects of Nuclear Weapons 1/	From NRDL-TR-187 2/	By Perkins-King 2/	By Knabe-Putnam 2/	Ratio of Results NRDL/ENW
1 minute	80	-	-	130	-
1 hour	.58	1.31	1.1	1.2	2.3
2 hours	2.52x10^{-1}	5.30x10^{-1}	4.4x10^{-1}	5.0x10^{-1}	2.1
6 hours	6.76x10^{-2}	1.17x10^{-1}	1.1x10^{-1}	1.2x10^{-1}	1.7
12 hours	2.94x10^{-2}	5.22x10^{-2}	4.4x10^{-2}	4.4x10^{-2}	1.8
1 day	1.28x10^{-2}	2.00x10^{-2}	1.7x10^{-2}	1.7x10^{-2}	1.6
36 hours	7.89x10^{-3}	1.10x10^{-2}	1.0x10^{-2}	1.0x10^{-2}	1.4
2 days	5.57x10^{-3}	7.10x10^{-3}	7.0x10^{-3}	7.0x10^{-3}	1.3
3 days	3.42x10^{-3}	4.20x10^{-3}	4.0x10^{-3}	4.0x10^{-3}	1.2
1 week	1.24x10^{-3}	1.67x10^{-3}	1.5x10^{-3}	1.5x10^{-3}	1.3
10 days	8.06x10^{-4}	1.17x10^{-3}	1.1x10^{-3}	1.1x10^{-3}	1.5
2 weeks	5.39x10^{-4}	8.20x10^{-4}	8.0x10^{-4}	8.0x10^{-4}	1.5
1 month	2.22x10^{-4}	3.40x10^{-4}	3.4x10^{-4}	3.4x10^{-4}	1.5
3 months	5.80x10^{-5}	6.90x10^{-5}	7.6x10^{-5}	7.5x10^{-5}	1.2
6 months	2.49x10^{-5}	2.60x10^{-5}	2.6x10^{-5}	2.3x10^{-5}	.96
1 year	1.10x10^{-5}	4.90x10^{-6}	5.0x10^{-6}	5.0x10^{-6}	.45
2 years	4.77x10^{-6}	6.60x10^{-7}	-	7.4x10^{-7}	.14
3 years	2.93x10^{-6}	3.75x10^{-7}	-	2.3x10^{-7}	.13
5 years	1.59x10^{-6}	2.18x10^{-7}	-	-	.14
10 years	6.91x10^{-7}	1.68x10^{-7}	-	-	.24
30 years	1.86x10^{-7}	1.13x10^{-7}	-	-	.61
60 years	8.12x10^{-8}	6.40x10^{-8}	-	-	.79
100 years	4.38x10^{-8}	3.06x10^{-8}	-	-	.70

1/ Based on the t$^{-1.2}$ law, average gamma photon energy = .7 Mev, 1 kt = 300 megacuries gamma activity at 1 hr. (no indication whether slow or fast fission of U-235, Pu-239 or U-238)

2/ Thermal neutron fission U-235

TABLE 2[1]

COMPARISON OF GAMMA DOSE RATES AND INTEGRATED DOSES FOR UNIFORM CONTAMINATION LEVEL OF 1 KILOTON OF FISSION PRODUCTS PER SQUARE MILE

	Dose Rate (r/hr 3 feet Above Infinite Plane)			Integrated Dose from 1 Hour (roentgens)	
Time After Detonation	Effects of Nuclear Weapons	NRDL-TR-247	Ratio NRDL/ENW	Effects of Nuclear Weapons	NRDL-TR-247
1 hour	1260	3360	2.7	0	0
2 hours	548	1416	2.6	815	2,199
6 hours	147	317	2.2	1898	4,706
12 hours	64	142	2.2	2467	5,950
24 hours	28	55	2.0	2964	7,012
48 hours	12.1	20.2	1.7	3407	7,803
3 days	7.43	11.52	1.6	3629	8,163
1 week	2.70	4.56	1.7	4042	8,831
2 weeks	1.17	2.21	1.9	4333	9,357
1 month	.483	.902	1.9	4612	9,898
2 months	.204	.329	1.6	4826	10,297
3 months	.126	.197	1.6	4939	10,481
6 months	.0547	.0792	1.4	5122	10,750
1 year	.0238	.0137	.58	5273	10,911
2 years	.0104	.00185	.18	5399	10,953
3 years	.00637	.00108	.17	5475	10,965
5 years	3.45×10^{-3}	6.24×10^{-4}	.18	5557	10,979
10 years	1.50×10^{-3}	4.80×10^{-4}	.32	5657	11,002
20 years	6.52×10^{-4}	3.94×10^{-4}	.63	5735	11,040
30 years	4.01×10^{-4}	3.26×10^{-4}	.81	5782	11,071
60 years	1.75×10^{-4}	1.82×10^{-4}	1.04	5847	11,136
100 years	9.46×10^{-5}	9.12×10^{-5}	.96	6080	11,183

[1] This paper was prepared on the assumption that 1 kt = 1.34×10^{23} fissions. A more accurate conversion is 1 kt = 1.45×10^{23} fissions. Since the doses and dose rates computed by NRDL were expressed as r (or r/hr) per 10^4 fissions per square foot, the NRDL results listed in Table 2 should be increased by the ratio $\frac{1.45}{1.34} = 1.08$

Representative HOLIFIELD. Our next witness is Dr. Machta of the U.S. Weather Bureau who will also testify on this subject.

STATEMENT OF DR. LESTER MACHTA,[1] U.S. WEATHER BUREAU

Dr. MACHTA. Thank you, Mr. Chairman.

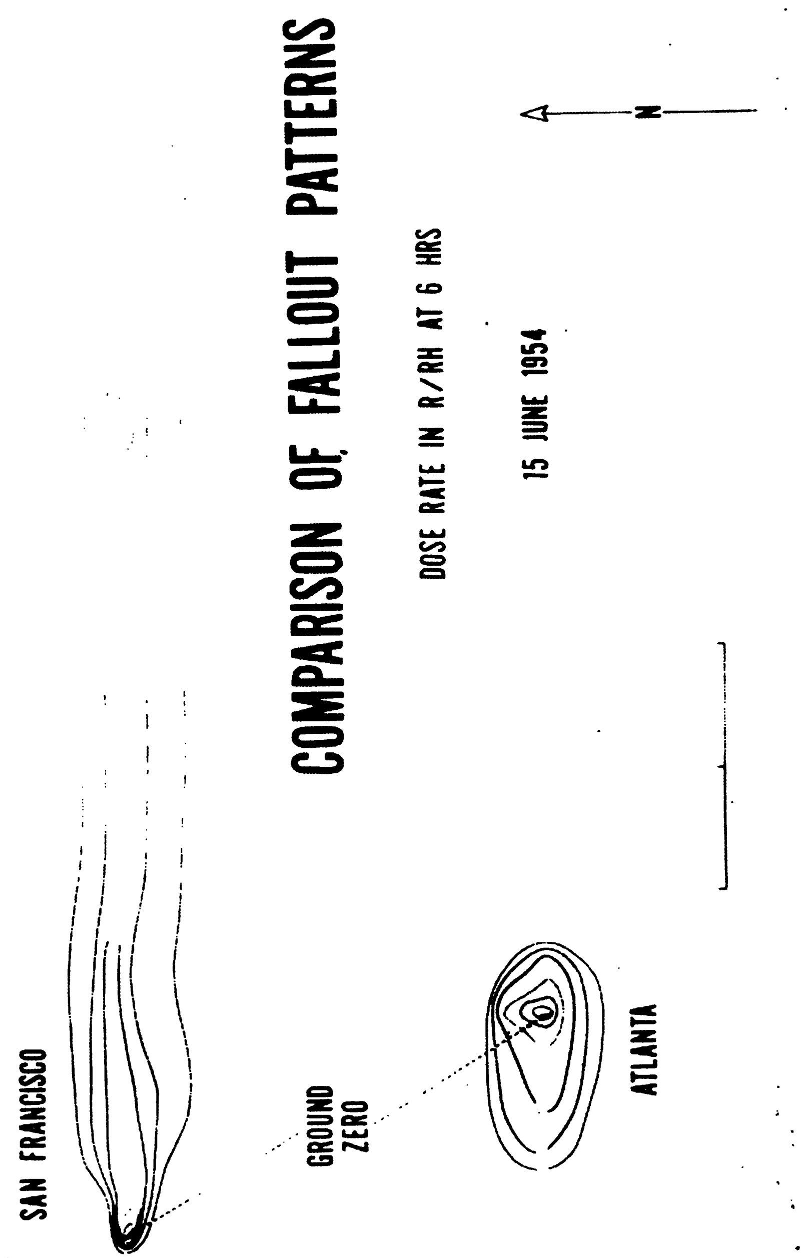
This presentation will describe the role of the atmosphere in the fallout problem. General principles will be reviewed and then applied to the attack patterns already given to the committee. Since the meteorological arguments pertaining to worldwide fallout have been stated, we will only discuss OCDM local fallout patterns. Certain aspects such as the role of meteorology in weathering are only being introduced. They will be covered in detail by subsequent witnesses.

WEATHER AND FALLOUT

The weather plays a major role in determining the location and distribution of radioactive fallout. The debris is carried by the winds far from ground zero as it settles through the atmosphere. A wind from the south means that towns to the north will be affected by fallout; winds from the west produce fallout in areas to the east of a target. Strong winds stretch the patterns out, reducing the heavy fallout near the target but increasing it at greater distances. This difference in fallout distribution can be observed in the first placard (fig. 1), taken from the testimony of Dr. Kellogg of the Rand Corp. in the 1957 fallout hearings. It shows isolines of fallout for two cases which are identical in every respect except for the winds. The winds associated with the long pattern at San Francisco from west to east and quite strong at almost all levels. The oval shaped pattern at Atlanta was based on winds which were extremely light at all levels. The shading represents the same dosages in both patterns. It is clear that the meteorological winds hold the key to where the fallout should occur. Incidentally, it is our opinion that any wind currents created by the nuclear explosions or subsequent fires will not appreciably modify nature's winds.

[1] See biographical sketch, p. 56.

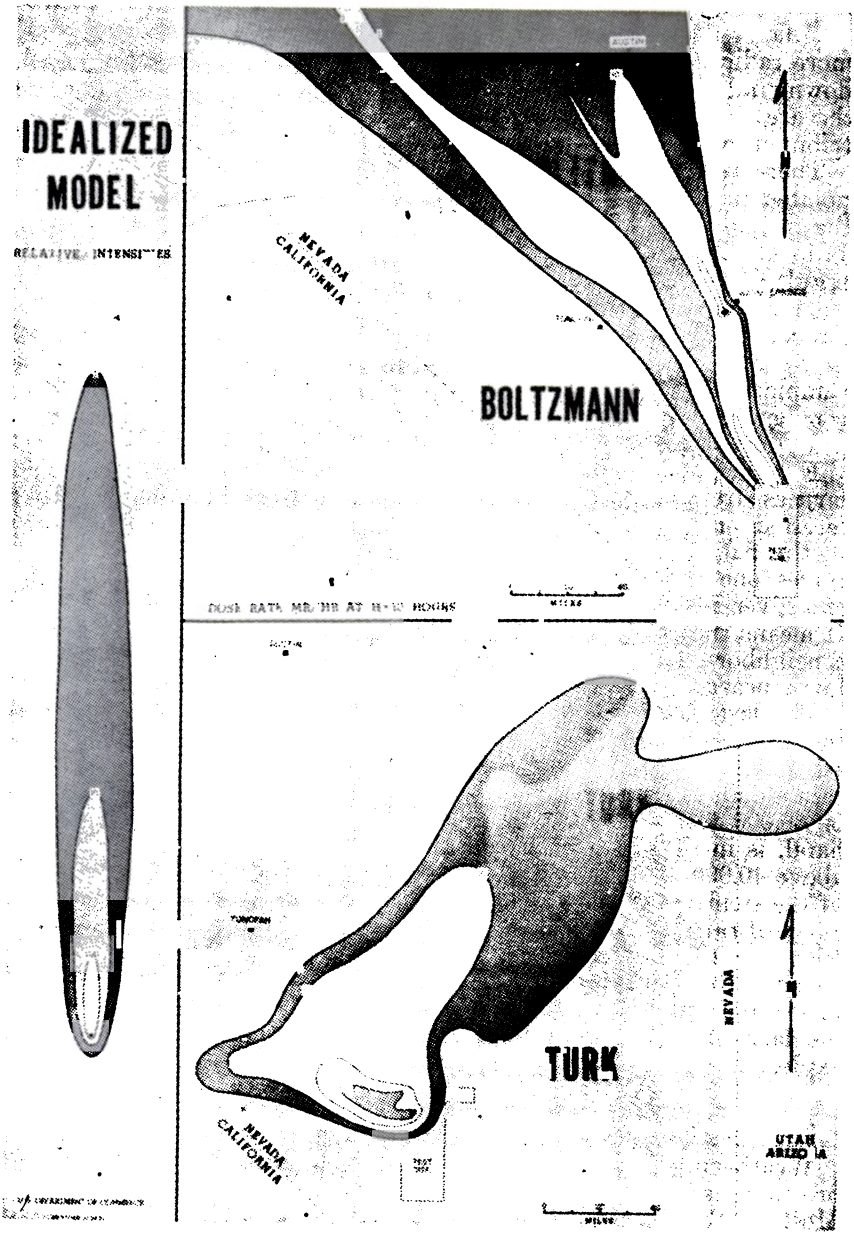
FIGURE 1


COMPARISON OF FALLOUT PATTERNS
DOSE RATE IN R/RH AT 6 HRS
15 JUNE 1954
N
SAN FRANCISCO
GROUND
ZERO
ATLANTA

The preparation of the OCDM patterns, which form the basis for so much of this committee's work, used the winds for the attack day. Since it was not particularly relevant for the purposes of this exercise that each line be exactly correct, approximate methods were used, namely idealized cigar-shaped patterns. In pointing this out, no criticism is implied. In fact, the maps were prepared by my associates, the Weather Bureau staff assigned to OCDM in Battle Creek. Rather, the purpose of the present discussion is to show how real fallout patterns are likely to look.

The small amount of fallout data for the March 1, 1954, H-bomb explosion in the Marshall Islands permits one to draw isolines of fallout in the shape of a cigar without seriously contradicting any of the observations. But when we have many fallout observations, as in the Nevada tests, the patterns depart markedly from cigar shapes. Placard 2 (fig. 2) shows two examples of fallout in Nevada. The drawing at the bottom shows isolines of fallout from the Turk shot on March 7, 1955, while the picture on the top is the Boltzman shot on May 28, 1957. Incidentally, the map which Dr. Triffet showed illustrated only the first 5 miles of the fallout. This figure contains the fallout 100 miles downwind. Neither pattern in placard 2 looks like a cigar or like the idealized picture shown on the left which was used in preparing the OCDM fallout map.

FIGURE 2


IDEALIZED
MODEL
BOLTZMANN
NEVADA
CALIFORNIA
TURK
NEVADA
CALIFORNIA
NEVADA
UTAH

I have chosen the Boltzman shot as an example for an additional reason. Approximately 6 miles west of Warm Springs, in an unpopulated region, a hot spot was found that was about seven times more radioactive than its surroundings. This region is immediately downwind of a mountain range and some light rain was reported in the area at the time. One or both of these factors may have contributed to the anomalously high fallout.

There is some doubt whether the results in Nevada can be extrapolated to less mountainous areas of the world and to explosions in the megaton rather than kiloton range. Monitoring of radioactive fallout from megaton sized tests in the Pacific suggests the same irregularities but the data are suspect. However, I think it is the considered opinion of experts that fallout from a megaton explosion over flat country will give almost the same nonuniform fallout as that noted in Neveda. The irregularities are due to many factors, such as the complexities of radioactivity in the atomic cloud, the effect of water condensation within the mushroom, atmospheric turbulence, as well as the roughness of the ground on which fallout takes place.

For purposes of this or similar exercises, to repeat, these irregularities are unimportant in evaluating casualties since we are interested only in statistics. But, in real fallout, the irregularities in the pattern complicate the work of evaluating the damage and forces one to rely almost exclusively on readings of radioactivity at a given place, rather than estimating them from adjacent locations. It means that if your town has a comparatively low fallout reading, a neighboring town further downwind need not necessarily have as low a measurement.

The last item to be considered is the effect of rain. The tops of the average rainbearing clouds are about 10,000 to 20,000 feet in altitude, but there are important exceptions. Some well developed rain clouds like thunderclouds and hurricane clouds extend to 40,000 or 60,000 feet. The bulk of the fallout radioactivity, on the other hand, is in the mushroom head of the cloud, the base of which lies above 40,000 feet. The particles in the lowest 10,000 to 20,000 feet of the stem are very large and fall almost as fast as raindrops. The effect of rain is therefore much less important than might be thought. Places with thunderstorms will probably have fallout manyfold higher than similar dry regions but other kinds of rain or snow would probably influence the fallout but slightly. It must be admitted that the lack of actual local fallout information in rain from megaton explosions prevents us from being sure of ourselves on this point.

WEATHERING

Weathering is the influence of meteorological factors in moving or otherwise modifying the radioactivity after it has been deposited. Most of the time weathering has a beneficial effect but there are exceptions as we will see in a moment.

The two prime meteorological factors which modify the fallout field are rain and ground level wind. Let us discuss the problem of rain first.

Runoff from rain modifies the fallout field mainly by carrying the particles from one place to another. Secondarily, the water washes the particles deeper into the soil. The effectiveness of the weathering depends strongly on the kind of ground; weathering is more effective with sloping terrain and less porous soil. Thus, it is rather obvious that sloping surfaces will tend to be denuded of radioactive particles while the low areas, like drainage basins, will tend to accumulate radioactivity. Time may also play a role. Light rains and dew may dissolve some of the radioactivity which then becomes fixed in the soil so that later heavy rains beocme less effective in moving the radioactivity.

Smooth surfaces like streets or other paved areas retain particles very poorly. But it must be remembered that what is washed from the streets either goes into sewers or runs off to the nearby soil which may or may not reduce the overall hazard.

One of the few documented examples of rain weathering took place on Rongelap Island. The first rain occurred 10 days after the deposition on this atoll of radioactive debris from the March 1, 1954, H-bomb test. The Geiger counter readings dropped by a factor of about 2 as a result of this tropical shower. Subsequent rains seemed to have little or no further effect. One must be cautious in assuming that the benefit found in this isolated case in the Pacific area is typical for the United States.

Next, consider weathering by wind action. The motion of air over the earth's surface can lift particles and carry them to other places. The degree of this kind of weathering depends on the wind speed and the particle sizes. It turns out that the particle sizes which we find in fallout in Nevada and in the Pacific are in the readily erodible class. In general, erosion tends to make the fallout field more uniform. This benefits high fallout areas by blowing the dust to adjacent, less hard hit places. On a smaller scale, just as with blowing snow, radioactive particles can pile up in certain preferred areas, and be scoured from others. Thus, where there are buildings, trees and and so forth, the effect of wind is to decrease the fallout preferentially in some places but increase it in others.

Wind makes the particles airborne. This may alter the external gamma exposure to people and increase the inhalation hazard and the possibility of beta burns after the fallout has ceased.

As with the case of rain, the nature of the surface on which the particles are resting plays an important role. The effect of wind erosion is much greater over a paved surface or disturbed soil which is dusty anyway. Also, as with rain, it is likely that the particles will be less vulnerable to wind weathering with the passage of time.

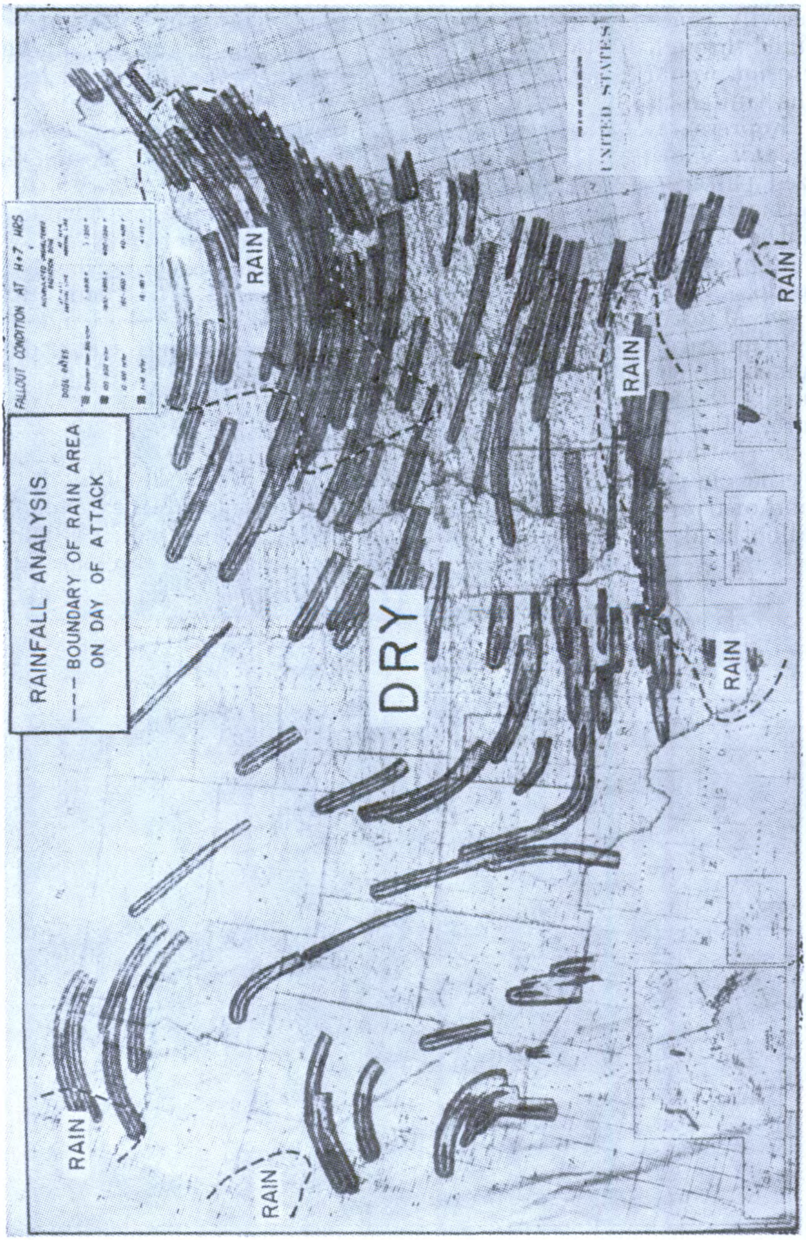
We have some experience in fallout weathering only in the sandy soil of Nevada. Here, under most conditions of wind erosion there is insignificant weathering, less than a factor of 2 decrease due to particles being blown away. Occasionally, with very high winds, we have observed a depletion by as much as a factor of 2 to 6.

It is known that the roads around the Nevada proving grounds contain less fallout than on the adjacent soil. Of course, the roads are also swept clean by the movement of vehicles as well as by the wind. The Public Health Service personnel in Nevada must monitor at about 25 feet off the road to obtain a representative reading.

APPLICATION TO ATTACK

On placard 3 (fig. 3), we have overlaid the early fallout by the rain area on the attack day. The largest region of rainfall extends from Ohio to Maine, the same part of the United States which is hardest hit by the attack. The rain in this area might increase the fallout

FIGURE 3


RAINFALL ANALYSIS
BOUNDARY OF RAIN AREA ON DAY OF ATTACK
FALLOUT CONDITION AT H+7 HRS
UNITED STATES
RAIN
RAIN
RAIN
RAIN
RAIN
RAIN
DRY

slightly. Even though the rain was not heavy, less than half an inch during the day, the decontamination in the many towns downwind of targets would be beneficial. Roofs would have been cleansed and paved areas washed. But, on the other hand, the rainwater would be too heavily contaminated for use as drinking water. The winds were light throughout the most of the country so that little or no wind erosion would be expected. In fact, the middle and western part of the United States enjoyed fine weather on this October day.

Representative HOLIFIELD. If these irregular patterns, which you are now showing us, had been used on this map rather than the idealized patterns which were used, what would the effect have been in terms of intensity of radioactivity in the different areas?

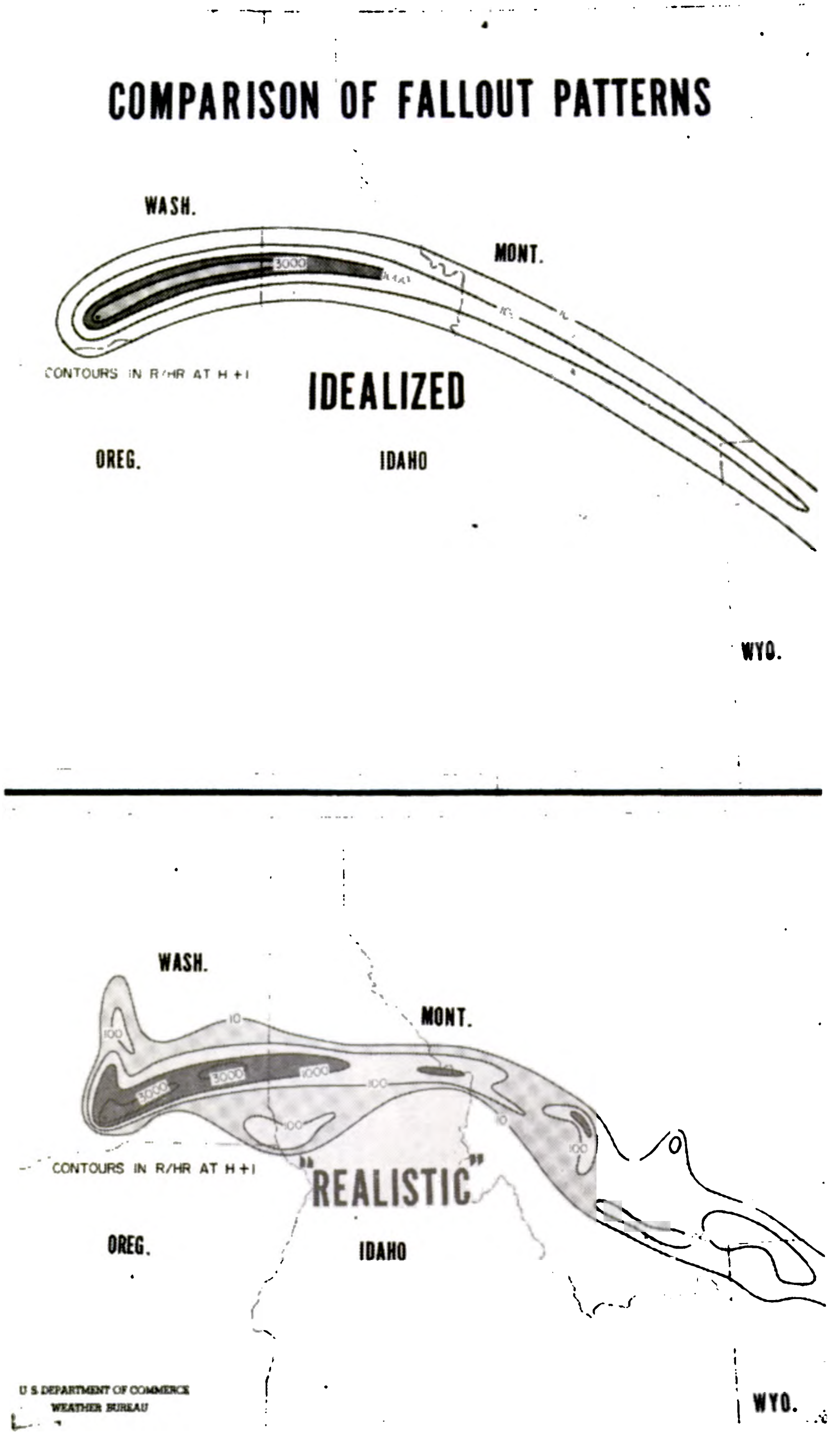
Dr. MACHTA. May I show this on the very next placard, sir?

Representative HOLIFIELD. I am anticipating what you are going to do.

Dr. MACHTA. Yes, sir.

In placard 4 (fig. 4), we show the pattern of fallout from the assumed attack on Hanford in southeast Washington State. The picture at the top follows the idealized pattern found in the OCDM picture. The picture on the bottom is our impression of what a "realistic" pattern might look like. We make no pretense of greater correctness in positioning the lines. They are shown only to indicate the kind of irregular pattern which would probably be present in a "real" fallout field.

FIGURE 4


COMPARISON OF FALLOUT PATTERNS
WASH.
MONT.
3000
CONTOURS IN R/HR AT H+1
IDEALIZED
OREG.
IDAHO
WYO.
WASH.
MONT.
10
100
3000
3000
1000
100
100
10
100
CONTOURS IN R/HR AT H+1
"REALISTIC"
OREG.
IDAHO
U S DEPARTMENT OF COMMERCE
WEATHER BUREAU
WYO.

In general the amount of fallout is the same. It would simply be distributed differently and much more irregularly.

Representative HOSMER. May I ask, in so doing, do you find that there would be generally an increase in the number of areas where there was an intensely high radiation or would it average out about the same?

Dr. MACHTA. My impression would be that it would average out, and the overall statistics would be about the same.

Representative HOLIFIELD. In other words, the overlapping of the irregular size would not necessarily contribute to an accumulation of intensity.

Dr. MACHTA. No. The same 80 percent total fallout would be present in both an irregular and idealized pattern. What you would add to one area, you would subtract from another.

Representative HOLIFIELD. Would it lend itself then to nonuniformity of reading, and therefore create more hot spots and cool spots than in the idealized pattern?

Dr. MACHTA. The answer is "Yes," it would lend itself to more hot spots and cool spots than the idealized patterns. Very definitely.

Representative HOSMER. I asked you a question a minute ago in which you gave the opposite answer, and I thought it was the same question. Would there be more areas of greater intensity or less? You said it would be about the same. You tell Mr. Holifield it would be different. What is it?

Dr. MACHTA. My point is that if you look at the red area of the chart at the top and the red area at the bottom, the areas when summed together would be the same. The hotter isodose line in the lower part of the figure is broken up and there are more isolated areas of intense fallout. The total area would be the same.

Representative HOSMER. In other words, we are going to get about the same total area within the 3,000 r. line, whatever happens.

Dr. MACHTA. That is right.

Representative HOSMER. It is just a question where the line is.

Dr. MACHTA. That is right. But it makes the problem of civil defense more difficult. You cannot assume that because you have a certain reading at one place, another place downwind will get a lower reading. It may have a higher reading.

Our final exhibit (fig. 5) shows the total rainfall during the 2 weeks after the attack superimposed on the D plus 2-weeks fallout patterns of OCDM. Heavy rains occurred only along the east coast and the Pacific Northwest coast. These are the only regions in which appreciable rain decontamination might be expected. High winds were present only in the upper Midwest where the fallout patterns were isolated. People who moved out of the heavy fallout areas into nearby uncontaminated regions in, say, North Dakota, might be surprised again by experiencing radioactivity, as a result of redeposition, although it would not be very heavy.

I wish to conclude with two points. First, please remember that the idealized fallout patterns are used for exercise purposes only and that real fallout pictures are much more complicated. Second, do not expect nature to significantly reduce the radioactivity from such an attack by weathering. The countermeasures will have to be man's own doing.

FIGURE 5


RAINFALL ANALYSIS
--- RAINFALL IN INCHES DURING TWO WEEKS FOLLOWING ATTACK
DRY
DRY
DRY
DRY
DRY
WET
WET
WET
WET
3
5
1

SUPPLEMENTARY STATEMENT OF DR. MACHTA

This memorandum is an attempt to present another viewpoint on the subject of the new NRDL conversion of kilotons per square mile to roentgens per hour at 1 hour. The "Effects of Nuclear Weapons" states that a uniform deposition of 1 kiloton equivalent of fission products over a square mile will give (in the absence of self-absorption, shielding or other terrain effects) about 1,260 roentgens per hour at 1 hour at 3 feet above the ground from gamma emitters. NRDL says it should be 3,350 roentgens per hour. For this reason, the chairman of the subcommittee felt that the OCDM patterns should be raised by a factor of 2 to 3.

However, it is the opinion of this writer that the starting point should be actual observations of fallout. Thus, the idealized AFSWP model is, indirectly, based on a real fallout case; that is, a bomb of a certain yield detonated on the ground produced a pattern of gamma emitting fission products as given in the model. Actually, some scaling due to yield is almost invariably necessary, but this is a secondary matter at this point. Further, the actual fallout is measured hours or days after H+1 but referred to H+1 by the use of the $t^{-1.2}$ law. This also introduces an error which is thought to be small, since the departure from $t^{-1.2}$ during the first few days is not great. All fallout patterns, with few exceptions, start with real fallout from a known yield device.

There are two problems. First, how should we decay (or grow) the dose rate from the observed values at specific times? This problem does not, in my opinion present serious errors, as just mentioned, so long as the period of interest is limited to the first few days. The second and unresolved problem is the fraction of fission products which is found in the local fallout. The AFSWP idealized model with the conversion given in the "Effects of Nuclear Weapons" yields about 80 percent local fallout and leaves 20 percent for worldwide fallout. But, if the same fallout pattern is used, the NRDL conversion would give 30 percent local fallout. Presumably the remaining 70 percent of the fission products would be the worldwide fallout. It is here that the difference in the conversion presents a problem rather than in the OCDM patterns. Mr. Shafer and I used the "Effects of Nuclear Weapons" in preparing our patterns and were at least consistent with an analysis of the fallout patterns from tests, on which the AFSWP and other models of fallout from land surface megaton bursts were primarily based.

It should be pointed out that the fallout patterns from the past tests are by no means precisely known because of the scarcity of fallout measurements over the ocean areas.

It is my opinion that, along with a revision of the AFSWP idealized model, the AEC and DOD should make every effort to resolve the question of the material balance of the fission products.

Representative HOLIFIELD. Thank you, Dr. Machta. Your calculations of these patterns have been arrived at from actual readings.

Dr. MACHTA. Which patterns are you referring to?

Representative HOLIFIELD. The irregular type patterns.

Dr. MACHTA. The ones in Nevada are based on actual readings, yes, sir, on the roads and aerial reconnaissance over the Nevada area.

Representative HOLIFIELD. This caused you to draw the irregular pattern which you showed us on the previous map?

Dr. MACHTA. That is correct, sir. It is our view that this is what would be the case in the event of a nuclear war on the United States or a nuclear attack on any place. Dr. Triffet's data from the Pacific supported the same contention.

Representative HOLIFIELD. The deeper we get into this the more complicated we find it.

Dr. MACHTA. Yes, sir.

Representative HOLIFIELD. Are there any questions of Dr. Machta? If not, thank you again, Dr. Machta, for your testimony.

Dr. MACHTA. Thank you, sir.

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Representative HOLIFIELD. The next witness is Dr. G. S. Hurst from the Oak Ridge National Laboratory. Dr. Hurst, will you please come forward at this time?

STATEMENT OF G. S. HURST,[1] HEALTH PHYSICS DIVISION, OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TENN.

Dr. HURST. Mr. Chairman, I have no visual aids. We had planned to show slides, but these facilities are not available, so if the committee and members would look at the document which we brought, it contains all the illustrations.

This presentation is entitled, "Application of Radiation Dosimetry Studies to the Evaluation of Environmental and Biological Consequences of Nuclear War."

This paper is in two parts. I will read part A. Part B, by J. A. Auxier, will be turned in for the record.

Part A is entitled "Dosimetry of Direct Radiation from Nuclear Weapons."

Section 1 is the introduction.

The main objective of the dosimetry program, currently in effect at AEC contractor sites in the United States and at the Atomic Bomb Casualty Commission (ABCC) in Japan, is to provide a basis for the correlation of the biological effects of radiation on the Hiroshima and Nagasaki populations with the radiation dose. Two types of results from this study have important application to the problem of the evaluation of biological consequences of nuclear war:

(1) Before a complete evaluation of the consequences of nuclear war can be accomplished, one must know the relationship of biological damage in man to the radiation dose. The group of exposed individuals in Hiroshima and Nagasaki presents a unique opportunity for a study of the medical response of a large number of humans to radiation. A long-term study of medical effects in this group is in progress in Japan at the ABCC, operated by the U.S. National Academy of Sciences, National Research Council. The program is conducted in cooperation with the National Institute of Health of the Ministry of Health and Welfare of the Japanese Government, with participation of interested Japanese scientists.

(2) The program initiated for the determination of the radiation doses for individuals located in Japanese houses in Hiroshima and Nagasaki was designed so that results from it may be applied to any problem concerned with protection against prompt weapons radiation. With this more general objective in mind, weapons effects studies were set up to obtain (*a*) the neutron and gamma dose as a function of distance from various kinds of fission weapons, (*b*) the energy spectrum of neutrons and its dependence on distance, (*c*) the angular distribution of neutron and gamma radiation arriving at points located at various distances from the detonation, and (*d*) the shielding characteristics of various materials for prompt weapons radiation. These data are basic to the consideration of the protection afforded by any type of shielding structure, e.g., homes, offices, industrial buildings, and shelters for the general population, and by fox-

[1] Born: Pineville, Ky., Oct. 13, 1927; B.A., Berea College, 1947; M.S., University of Kentucky, 1948; Ph. D., University of Tennessee, 1959 (Capture of Electrons in Molecular Oxygen); Health Physics Division (Section Chief, Radiation Dosimetry Section), Oak Ridge National Laboratory, 1948 to present.

holes, armored vehicles, and special shelters for the military population.

Section II is basic radiation data.

In this section we give examples of weapons effects results which illustrate the type of data referred to in the introduction. All the examples are quoted for nominal fission devices (10 to 20 kilotons).

A. Gamma dose a function of distance

Figure 1 shows a typical air dose versus distance relationship for gamma rays. The gamma dose d(R) in rads is multiplied by the square of the slant range (R), in yards, from the point of detonation to the point of measurement and is divided by the weapon yield in kilotons (kt.). This quantity is then plotted as a function of the slant range in hundreds of yards. To obtain the gamma dose per kt. at some distance of interest, one reads the quantity $d(R)R^2$/kt. at the distance of interest and divides by the square of the slant range in yards. For example, the gamma dose at 1,000 yards is approximately 300 rads per kt.

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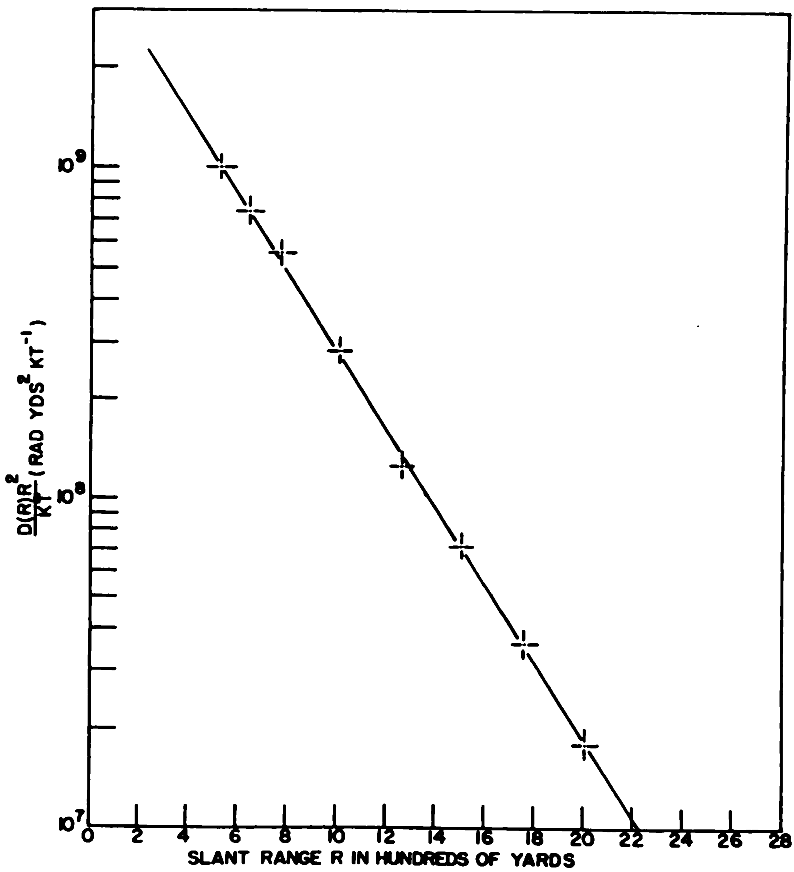

FIG. 1 GAMMA AIR DOSE vs SLANT RANGE FOR A TYPICAL NUCLEAR DETONATION

B. Neutron dose and neutron energy spectrum as a function of distance

Figure 2 shows the same type of presentation of the neutron dose for a typical weapon. For example, it is seen, using the scale to the right, that the neutron dose at 1,000 yards is approximately 350 rads per kt. Figure 2 also shows the energy spectrum of neutrons as a function of distance. The scale to the left represents the neutron flux f(R) (n/cm.²) multiplied by the square of the slant range and divided by the weapon yield in kt. Reading from the top curve down shows f(R) times R²/kt. for the total number of fast neutrons, slow neutrons, neutrons of energy greater than 0.75 Mev., neutrons of energy greater than 1.5 Mev., and neutrons of energy greater than 2.5 Mev., respectively. The fact that these curves are approximately parallel shows that the neutron energy spectrum is approximately independent of slant range.

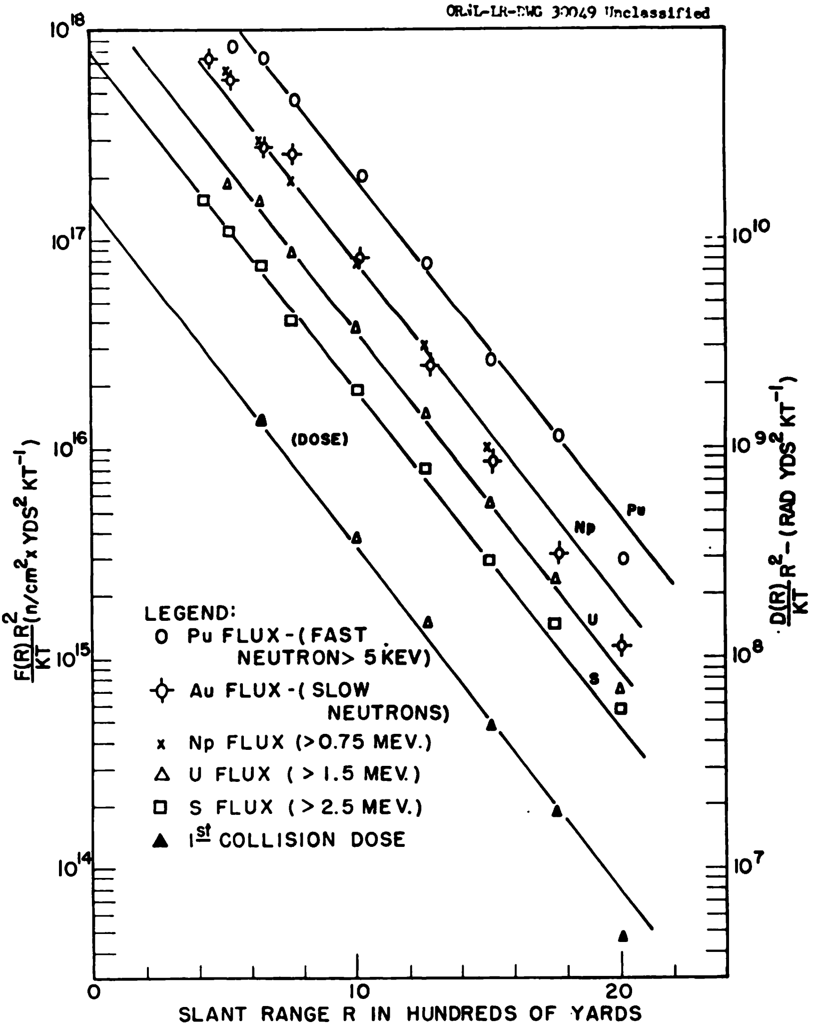

FIG. 2 NEUTRON AIR DOSE AND FLUX vs SLANT RANGE FOR A TYPICAL NUCLEAR DETONATION

C. Angular distribution of weapons radiation arriving at a point in space

At Operation Plumbbob (Nevada, 1957) the angular distribution of neutrons and gamma rays arriving at various distances from the point of detonation was measured. Figure 3 shows the coordinate system used in presenting the data. The angle theta is a polar angle measured from the line of sight to the burst point and p.s.i. is the azimuthal angle. A representative set of results for fast neutrons is shown in figure 4. The height of the column is proportional to the flux of neutrons and the area of the base of the column is proportional to the solid angle subtended by the measuring instrument. The same kind of presentation is used in figure 5 for the gamma ray dose.

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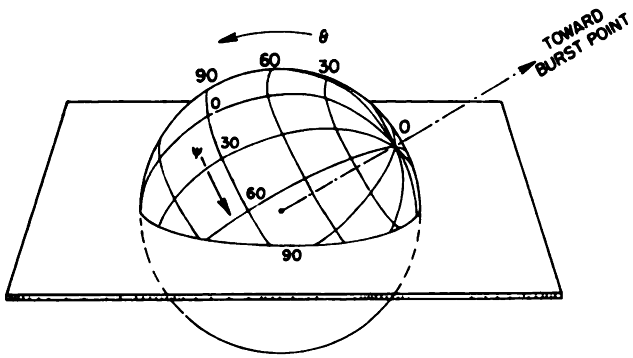

FIG. 3 DIAGRAM ILLUSTRATING THE COORDINATES θ AND ψ USED IN PRESENTING ANGULAR DISTRIBUTION

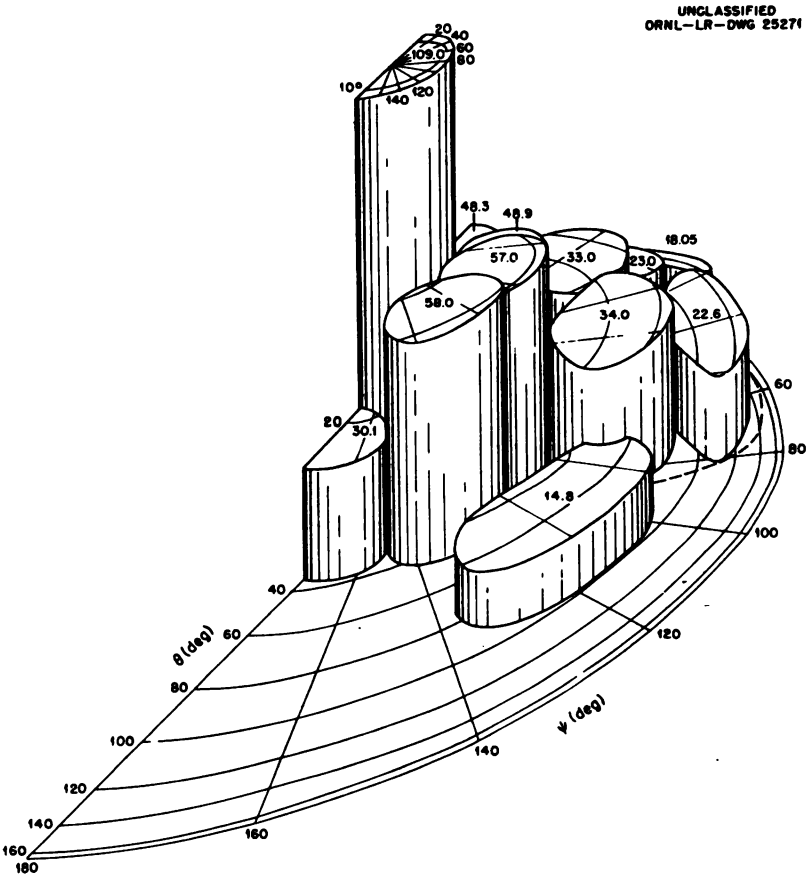

FIG. 4 ANGULAR DISTRIBUTION OF FAST NEUTRONS (> 5 KEV) FOR A TYPICAL NUCLEAR DEVICE

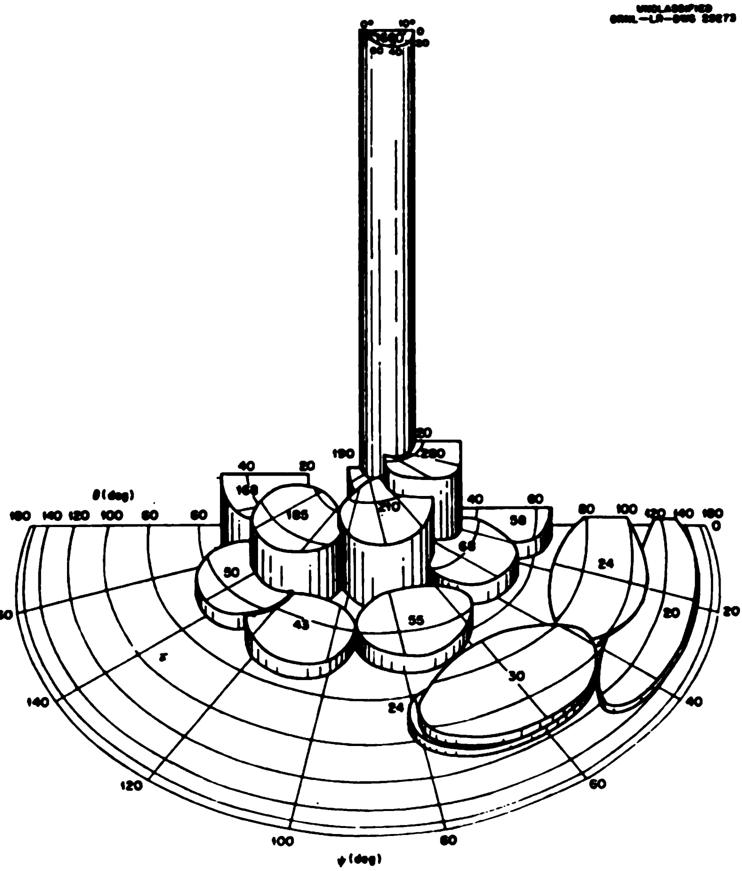

FIG 5 ANGULAR DISTRIBUTION OF GAMMA RAYS FOR A TYPICAL NUCLEAR DEVICE

D. Attenuation of weapons radiation by light frame houses

In Operation Plumbbob two light frame houses, representative of medium-sized Japanese residences, were exposed to weapons radiation. Gamma and neutron doses were measured at various points inside the houses. Figure 6 shows the results for neutrons. In this figure the ratio "dose inside house/air dose" is plotted as a function of the house penetration distance, i.e., the distance along the ray path measured from the point where the ray first enters the house to the point of detection. Results are shown for two houses of identical design but with opposite orientations with respect to the incoming radiation, and for two elevations above the floor (42 inches and 84 inches). Figure 7 shows the same type of results for gamma radiation. In both cases it is seen that the amount of protection which houses of this kind afford for prompt weapons radiation is small, amounting to about a factor of 2 for neutrons and appreciably less than a factor of 2 for gamma radiation.

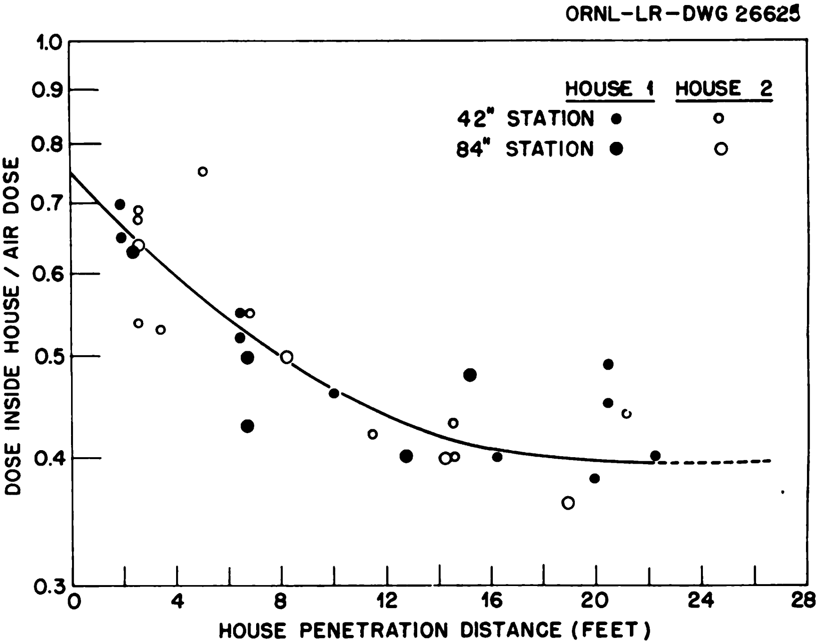

FIG. 6 ATTENUATION OF FAST NEUTRONS BY TYPICAL SINGLE STORY JAPANESE HOUSES

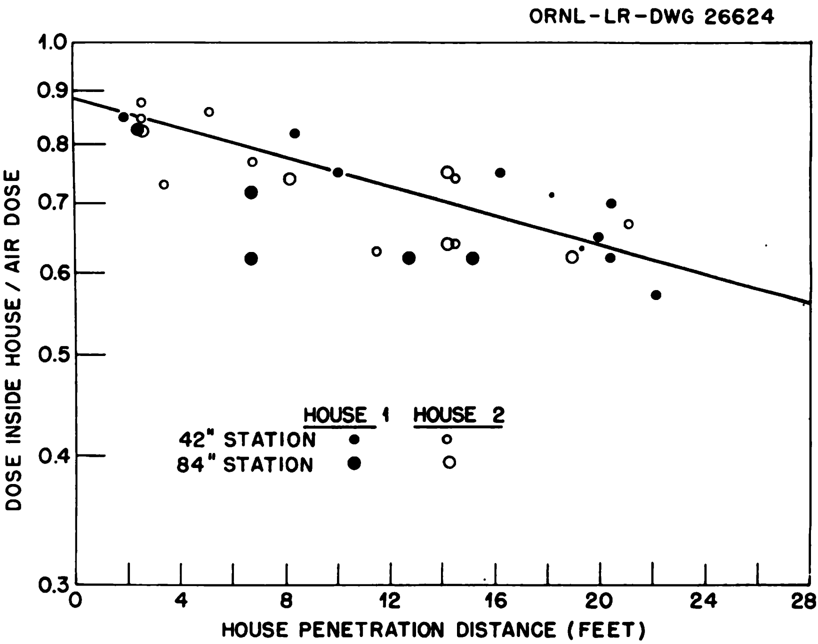

FIG. 7 ATTENUATION OF GAMMA RADIATION BY TYPICAL SINGLE STORY JAPANESE HOUSES

E. Mutual shielding in a cluster of light frame houses

In the Hardtack Phase II Operation (Nevada, 1958) seven houses, representative of Japanese design but constructed of substitute American materials, were used in three different experiments. The houses consisted of three sizes: (*a*) a medium-sized single story, (*b*) a large two story, and (*c*) a small single story. These houses were used in various arrangements to determine (*a*) the effect of house size and (*b*) the effect of mutual shielding. Some of the neutron data are quoted as an illustration of the type of results obtained.

The small single-story house attenuated the neutron dose to 0.51 (numbers given are the ratios of the doses inside the houses to the doses with no houses present) when used alone, but when placed behind the medium-sized single story house, i.e., the side farthest from the detonation, the neutron dose was reduced to 0.33, and when placed behind the large two story house the neutron dose was reduced to 0.29. When the large two story house was used alone the neutron dose on the first level was reduced to 0.41, and on the second level the neutron dose was reduced to 0.45. When the medium-sized single story house was placed alongside the large two story house, the dose on the first level was reduced to 0.35 and the dose on the second level was reduced to 0.44. Likewise, when the medium-sized single story house was used alone the neutron dose was reduced to 0.43, and when placed at the side of the large two-story house, the neutron dose was reduced to 0.37.

It is seen from these studies that even if a large house is placed in front of a small house the neutron dose inside the small house is not reduced by a large factor, which is consistent with the angular distribution work reported above.

More details of the information presented in this section can be found in an article by R. H. Ritchie and G. S. Hurst ("Health physics 1," 390, 1959) and in Weapons Tests Reports WT–1504 and WT–1725,

In conclusion, the angular distribution data, together with experimental data on the attenuation of plane slabs, were used to calculate the attenuation by the light frame structures. Theoretical and experimental results were in good agreement; thus it is reasonable to expect that the radiation protection afforded by various other kinds of structures can be obtained from the basic data on angular distributions and plane slab attenuation.

The main uncertainty in the present knowledge of the dose received by individuals being studied in Japan lies in the air dose. The most effective way to normalize the basic information presented above to the Japanese cases would be to detonate reconstructions of the two weapons fired over Japan. Air dose measurements from these devices would then complete the information needed on radiation dose and would provide a basis for the correlation of medical effects in Japan with radiation dose.

That completes the formal presentation, Mr. Chairman.

Representative HOLIFIELD. You have asked that part B be placed in the record at this point?

Dr. HURST. Yes, sir.

Representative HOLIFIELD. Without objection, that will be done at this point.

(The document referred to follows:)

PART B.—EVALUATION OF RESIDENTIAL STRUCTURES FOR SHIELDING AGAINST FALL-OUT RADIATION

(J. A. Auxier[1])

I. INTRODUCTION

An experiment for the evaluation of the shielding afforded by typical domestic houses against fallout radiation was conducted at the Nevada test site in the spring of 1958. Sponsored by the Division of Biology and Medicine of the AEC, the experiment was conducted by Oak Ridge National Laboratory in collaboration with the Office of Civil Defense and Mobilization, National Bureau of Standards, University of California Project Civil, and Tracerlab, Inc.

Specific objectives of the experiment were the measurement of the protection afforded by five typical American houses against extended sources of radiation on the ground and on the roof, and the improvement in protection provided by simple permanent or emergency modifications that a homeowner might make.

Experimental techniques employed are indicated in a general way in figures 8 and 9. Four hundred small Co^{60} gamma sources were placed at 2-foot intervals in flexible plastic tubing so that a large variety of source arrays were readily available. In general, the sources were used in circular patterns on the ground and in longitudinal patterns on the roofs with the source tubes separated by 2 feet. The houses had been built during earlier nuclear tests for other types of studies. Those used included one each of the following types: Two-story wood frame with basement, two-story brick and cinder block with basement, single-story wood frame, single-story concrete block with a flat roof of 6-inch-thick concrete, and a single-story precast concrete with 6-inch-thick walls and roof. A more complete description of these houses may be found in the following reports: ITR-1194, Operation Teapot; CEX-58-1; and in "The Effects of Nuclear Weapons."

[1] Born: Paintsville, Ky., Oct. 7, 1925. B.A., Berea College, 1951; M.S., Vanderbilt University, 1952: Physics and engineering department, the radiobiological laboratory of the University of Texas and the U.S. Air Force, Austin, Tex., 1952–55. Radiation Dosimetry Section (group leader, Dosimetry Applications Group), Health Physics Division, Oak Ridge National Laboratory, 1955 to present.

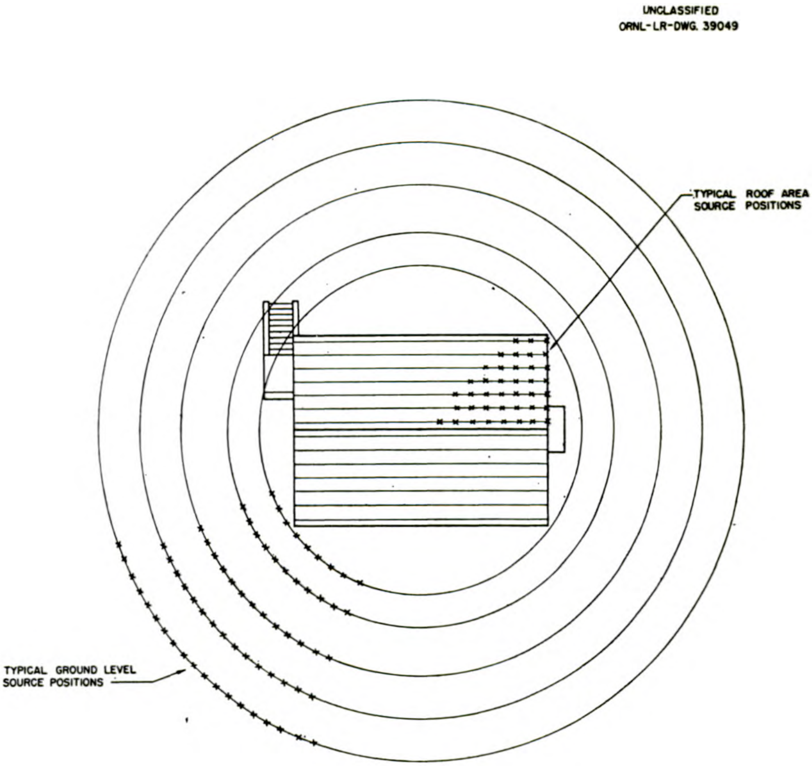

FIG. 8 TYPICAL SOURCE POSITIONS

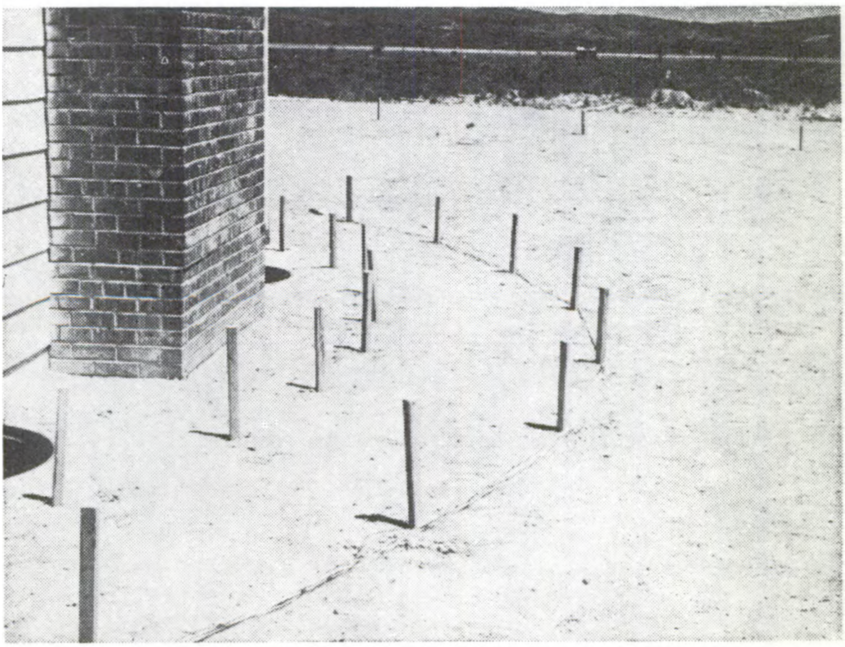

FIG. 9. TYPICAL SOURCE ARRANGEMENTS

II. GENERAL RESULTS

The dose rate was determined above a simulated fallout field on smooth level ground. Measurements of dose rate distribution were then made in the various houses for many source configurations including those for the infinite source field. Figure 10 shows generalized results of measurements in a house located in this type of field with sources also on the roof. The number at each point is the dose rate observed at that point relative to a point 3 feet above the infinite field (free space dose rate) expressed in percent. At a point near the center and 3 feet above the floor of a two-story light-walled structure such as a framed or shingled house, the dose rate was approximately 50 percent of the free space dose rate. Three feet above the center of the basement floor it was about 5 percent when the window wells were blocked by sandbags. In the corner of the basement the value decreased to about 2.5 percent. By placing a table or similar structure in the corner of the basement with 75 to 100 pounds of sand, dirt, concrete blocks or similar material on each square foot of table top, the dose rate was reduced to less than 1 percent of the free space dose rate.

Other modifications studied included the blocking of exterior openings in the precast concrete house with concrete blocks and building partial concrete block walls around parts of the one-story frame house. The effectiveness of this type modification varies strongly with position in the house. In general, the dose rates in single-story houses would be slightly higher than in two-story houses of the same construction. Dose rates in brick houses would be lower by 50 to 75 percent than in frame houses. Heavier structures such as precast concrete or concrete block yield a dose rate at the center of the first floor approximately 15 to 30 percent of the free space dose rate. In houses with basements, the best shielded areas are in the basements, particularly in corners away from windows.

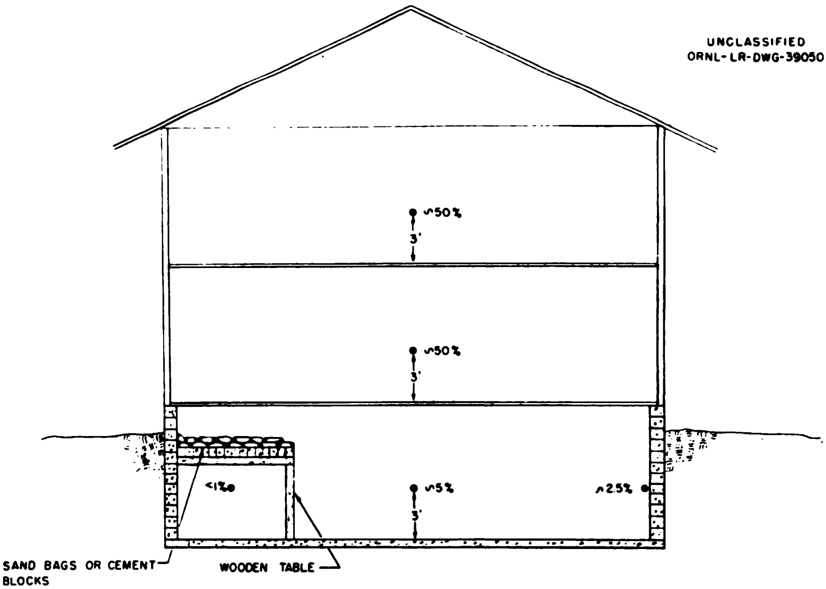

FIG. 10 PERCENT OF AIR DOSE FOR TYPICAL POSITIONS

Calculations based on these data, or normalized to them, permit extrapolation to a large variety of houses. In addition to the evaluation at ORNL, calculational programs of two different types are underway at NBS and at Project Civil. In addition, a theoretical study is underway in England and the workers there are utilizing the data available in the report of this experiment.

III. SHIELDING EXPERIMENTS WITH OAK RIDGE HOMES

To evaluate existing homes complete with normal furnishings and built on uneven and sloping terrain, a corollary experiment is being conducted in Oak Ridge, Tenn., by ORNL in collaboration with the AEC and local homeowners. Although not so basic as the study at the Nevada test site, the measurements in Oak Ridge will permit an extension of calculations based on the earlier fundamental data and will yield experimental information for analyzing the shielding already generally available to the population. In addition, the data will be directly applicable to many homes in the communities which were initially established because of the atomic energy program, and in which the AEC necessarily has a vital interest.

Mr. HOLIFIELD. I would like at this time to introduce a paper by Dr. Charles M. Eisenhauer of the Atomic and Radiation Physics Division of the National Bureau of Standards.

SHIELDING FROM FALLOUT RADIATION

(By Charles M. Eisenhauer [a])

In any realistic appraisal of the casualties that might result from fallout radiation, we must know how radiation dose rate levels are modified inside of buildings. Significant progress has been made during the past year, both in calculations and experiments, in obtaining answers to this question. I would like to indicate the nature of these calculations and experiments and to show some of the results which have been obtained.

I. THEORETICAL STUDIES AT THE NATIONAL BUREAU OF STANDARDS

For many years the National Bureau of Standards has been engaged in a program to study the basic penetration properties of nuclear radiations. About 3 years ago the Bureau undertook a study of the penetration of gama radiation in order to provide data on the penetration of fallout radiation into buildings. This work has been sponsored by the Office of Civil and Defense Mobiliaztion.

The penetration of fallout radiation into buildings is illustrated schematically in figure 1. In calculating the dose rates inside of a structure it has been assumed that fallout particles are uniformly distributed on the roof and on the ground surrounding the structure. It has been further assumed that no fallout particles lie inside of the building. Under these assumptions, all radiation that reaches a person inside of the building must originate from radioactive particles outside and must penetrate through the walls and roof of the building.

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[a] Born in New York City in 1930, Mr. Eisenhauer graduated from Queens College in 1951, where he majored in mathematics. He also did graduate work in physics at Columbia University. He has worked at Brookhaven National Laboratory in the field of experimental neutron physics and at the Armed Forces special weapons project on problems in gamma ray penetration. Now on the staff of the Atomic and Radiation Physics Division at the National Bureau of Standards, he is coordinating theoretical and experimental research on protection afforded by existing homes and structures against nuclear radiation. He is a member of the Radiation Shielding Subcommittee of the National Academy of Sciences Advisory Committee on Civil Defense.

FIGURE 1

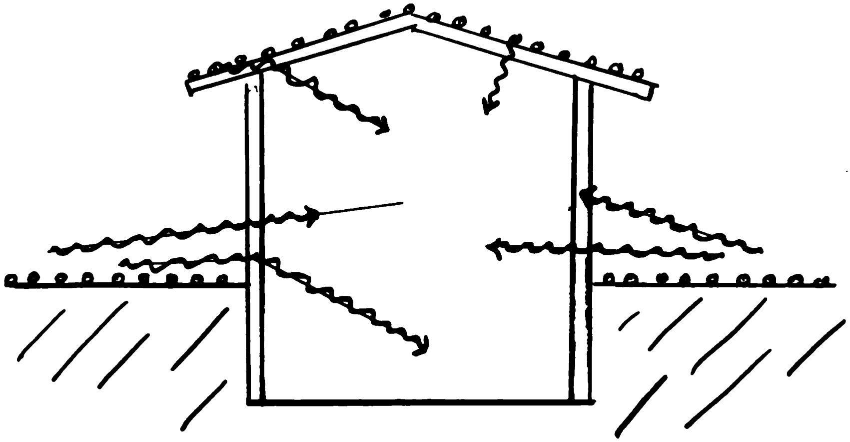

FIGURE 1.—Schematic drawing of a structure showing penetration of radiation into structure from fallout on the roof and on the surrounding ground.

In the case of a structure in a fallout field, as depicted in figure 1, there are gamma rays of many different energies and angles hitting the roof and walls of the building. Some of these rays pass through the walls or roof but others are either stopped in the walls or roof (absorption) or have their energy and direction changed (scattering). In order to solve this complex problem, it was first broken down into simpler problems and each variable studied separately. In order to do this, the whole procedure had to be coded on a high speed automatic computer.

In this procedure the roof, walls, and floors of a building are treated as barriers which reduce the intensity of the gamma radiation. The penetration of radiation through each barrier is studied separately. The ability of radiation to penetrate a barrier of thickness, X, depends on the material of the barrier, the incident energy, E, of the radiation and the angle, Θ, at which the radiation strikes the barrier. A schematic diagram of this general shielding problem is shown in figure 2. The solution of this problem shows in detail how the attenuation, or decrease in dose rates, depends on the barrier material, source energy, and the angle of incidence of the radiation.

A. *Barrier material*.—The attenuation as a function of the barrier thickness is shown in figure 3 for three different materials. The curves are for 1 Mev. gamma radiation perpendicularly incident on the barrier. The main reason why lead and iron appear more effective than concrete in reducing dose rates is that a given thickness of lead or iron weighs much more than the same thickness of concrete. The most important way of increasing shielding is to put the greatest weight of material possible between the source of radiation and the detector location.

FIGURE 2

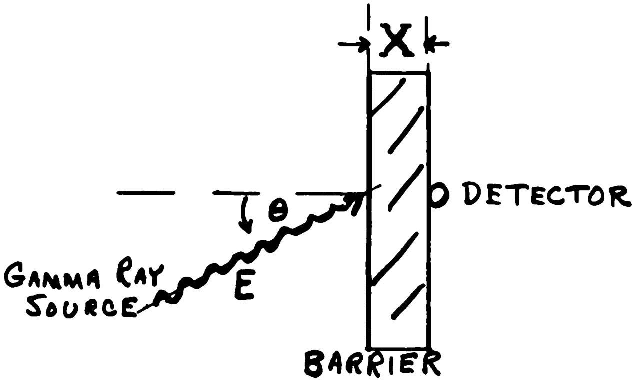

FIGURE 2.—Generalized shielding problem. Gamma rays of energy E strike a barrier of thickness X at an angle of Θ. The problem is to calculate the dose rate at a detector on the other side of the barrier.

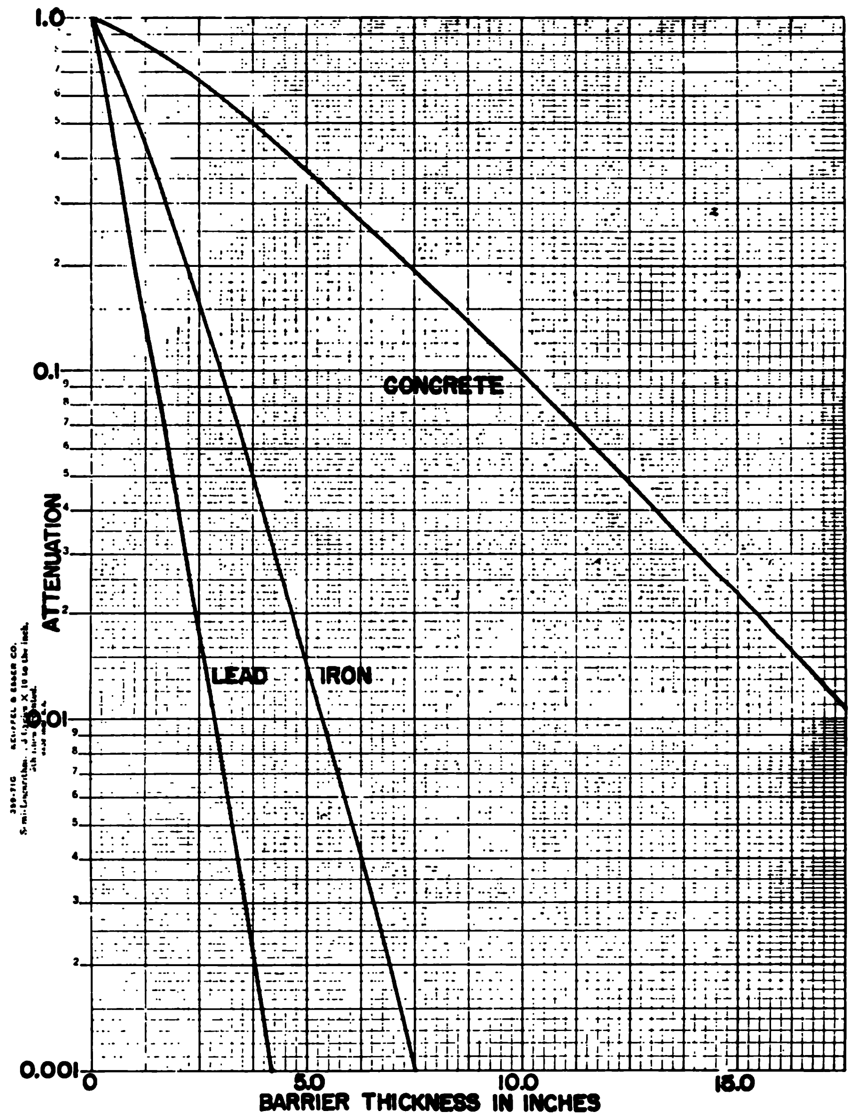

FIGURE 3.—Attenuation of gamma radiation dose as a function of barrier thickness for three different barrier materials. The curves were calculated for 1 Mev. gamma radiation perpendicularly incident on the barrier.

Most of the first calculations have been made for water and concrete barriers. Other materials such as iron and lead will be studied in the near future.

B. *Source energy.*—The dependence of the attenuation on the energy of the gamma radiation is shown in figure 4. The curves are for gamma radiation perpendicularly incident on a concrete barrier. It can be seen that it takes about 2½ times as much concrete to reduce the dose rate from a 5.11 Mev gamma ray by a factor of 10 as it does for a 0.511 Mev gamma ray.

The automatic computer codes are sufficiently general to cover a wide range of incident gamma ray energies. Because of the specific interest in fallout, however, many of the calculations have been made for that combination of gamma ray energies from the fission products which exist at 1 hour after time zero.

C. *Angle of incidence.*—The dependence of the attenuation on the angle of incidence of the radiation is shown in figure 5. The curves correspond to the penetration of gamma rays from fallout at 1 hour after weapon burst. It can be seen that the attenuation in 10 inches of concrete for zero degrees angle of incidence is about 100 times that for 80° angle of incidence. It is therefore very important to know at what angles the gamma radiation is incident on a barrier.

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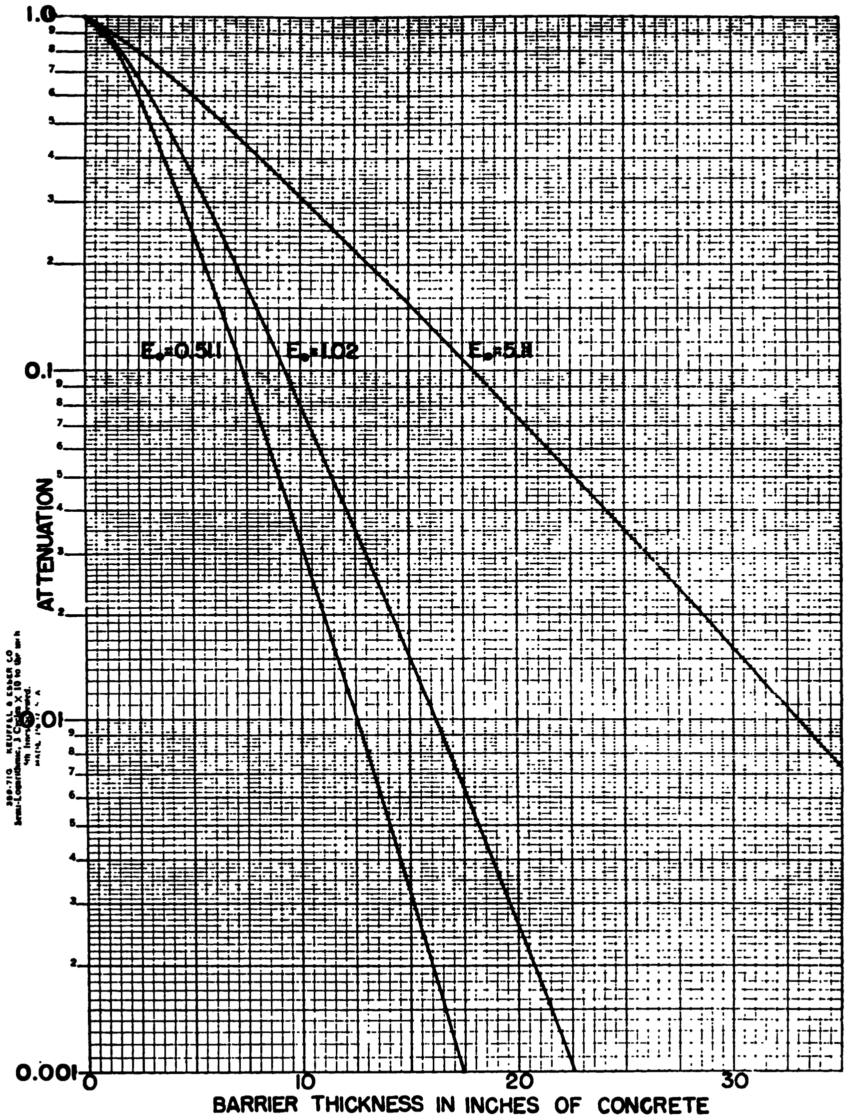

FIGURE 4.—Attenuation of gamma radiation dose as a function of concrete barrier thickness for three different gamma ray source energies. The units of E_o are Mev. The curves were calculated for gamma radiation perpendicularly incident on the barrier

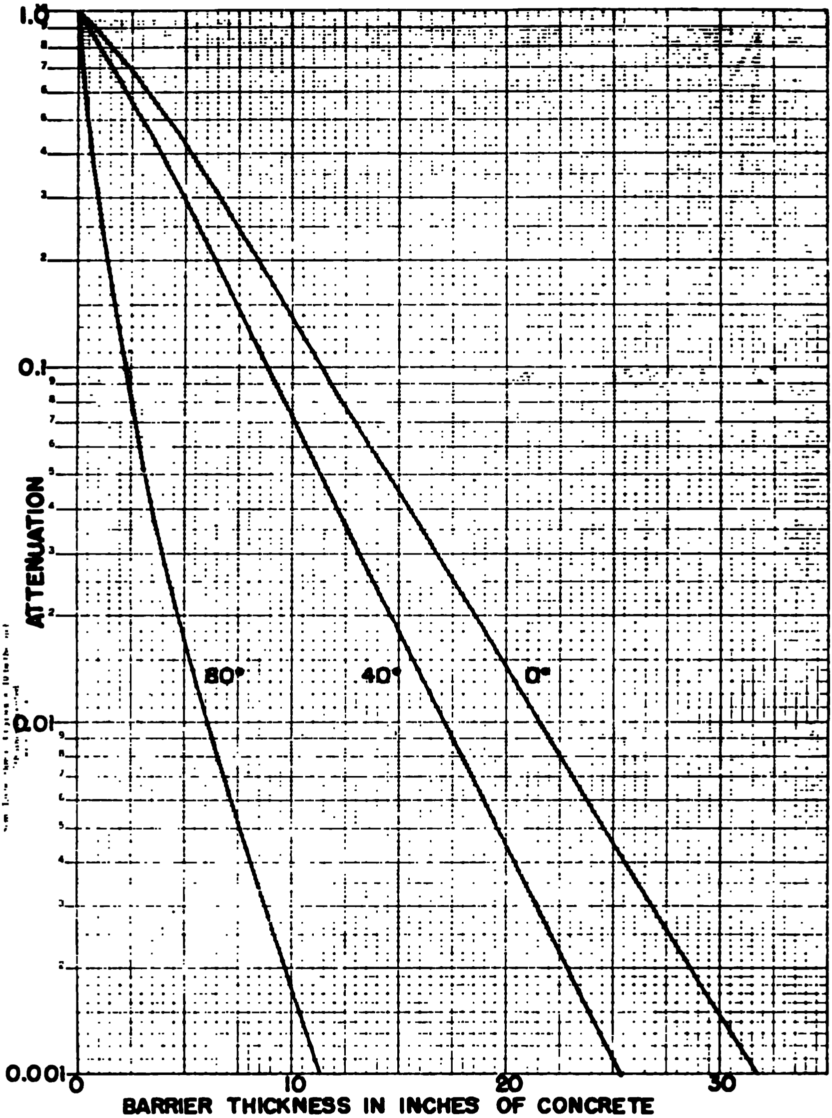

FIGURE 5.—Attenuation of gamma radiation dose as a function of concrete barrier thickness for three different angles of incidence. The curves were calculated for the energy distribution of fission product gamma rays at 1 hour after weapon burst.

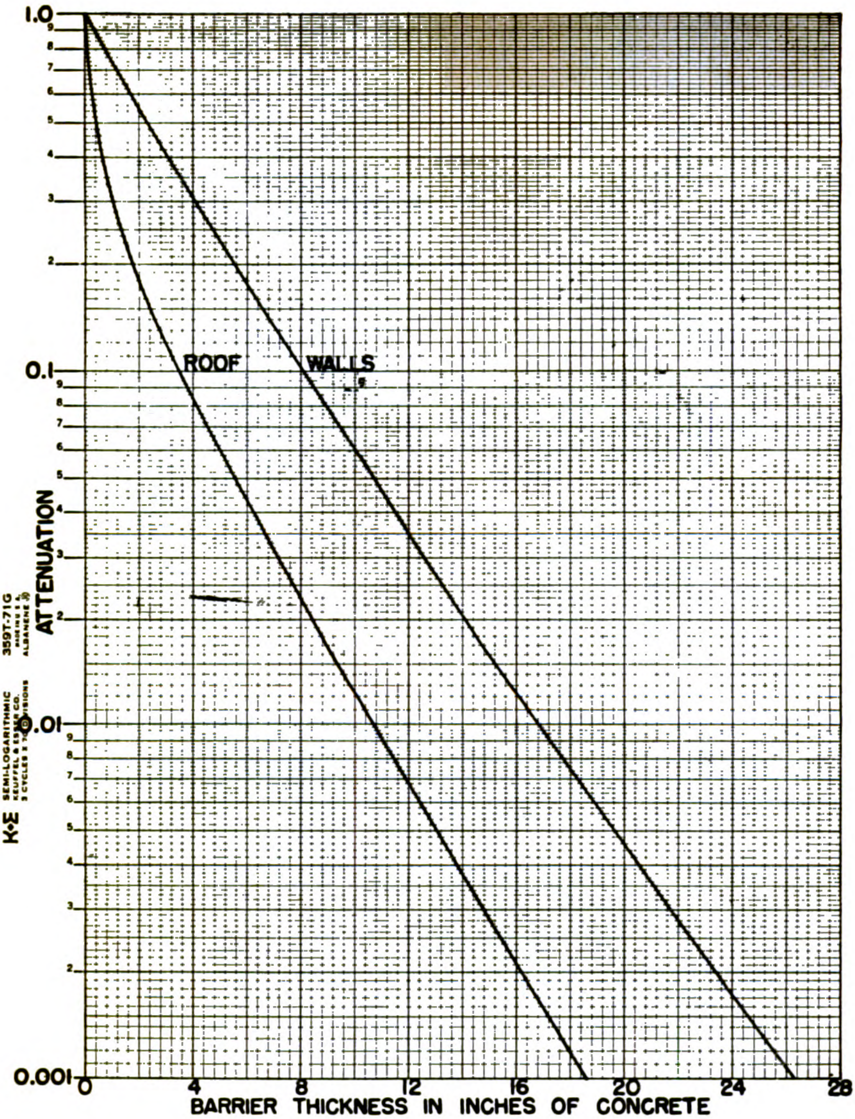

FIGURE 6.—Attenuation of gamma radiation dose as a function of concrete barrier thickness. The curve labeled "roof" gives attenuation of radiation from roof sources as it penetrates the roof and floors. The curve labeled "walls" gives the attenuation of radiation from ground sources as it penetrates the walls. Both curves were calculated for the energy distribution of fission product gamma rays at 1 hour after weapon burst.

Shielding calculations have been made for the combination of angles corresponding to radiation from fallout on the roof and radiation from fallout on the surrounding ground. Attenuation curves for the two types of sources are shown in figure 6. Although these curves were calculated for the energy distribution of 1-hour fission products, the qualitative differ-

ences between the two curves holds for all gamma ray energies. The radiation from the ground sources is more penetrating because it is more nearly perpendicular ($\Theta=0°$) than the radiation from roof sources.

The results of fallout calculations performed at NBS will be made available to the public in several manuals which are due to be published very soon. The first will be a basic technical manual written by Dr. Lewis Spencer who has been primarily responsible for the calculations (reference 15). This manual will be designed for the use of technical people and people who have had experience in shielding calculations.

Another manual will be published by OCDM and will present these calculations in a simplified form (reference 16). The purpose of this manual is to provide architects and engineers with a systematic approach to problems involving protection from fallout gamma radiation. The manual will give methods for designing new protective structures and for analyzing the protection afforded by existing structures.

A third manual which has already been published in an interim edition is a further simplified method for calculation radiation protection in structures (reference 7). This is designed for purpose of surveys where one needs a quick method for analyzing the shelter capabilities of a community. It has already been in use in several surveys and has been found very satisfactory.

With these results now available, we have been able to calculate the fallout protection in many types of buildings. This can be done more quickly and with more accuracy than was previously possible. For purposes of planning and survey the calculations have been used as a basis for grouping structures according to shielding categories. Each category represents a range of protection factors, where the protection factor is defined as the dose rate at 3 feet above the ground outside, divided by the dose rate at the specified location. Table 1, taken from the "Guide for Fallout Shelter Surveys" (reference 7), gives the shielding categories of many types of buildings.

An important result of this work is a much better understanding of how radiation penetrates into basements. In particular, we can specify how the dose rate in the basement depends on such factors as the fraction of the basement wall above ground level. We can also predict how the dose rate differs, for example, in the basement of a wood frame house from that in the basement of a brick house.

II. RECENT EXPERIMENTS

These calculations have been supplemented by a number of recent experiments which have given information on the radiation shielding of structures. A description of these experiments is given at the end of this section.

Most of the experiments have used radioactive cobalt 60 sources to simulate the radiation from fallout. In general these experiments have been performed by placing the radioactive source at various positions on the roof and on the ground surrounding the structure. Radiation detectors are placed at various points within the structure to measure how much radiation penetrates into the structure. The measurements are then combined to determine what the dose would be if the roof and ground were uniformly covered with radioactive material.

The first series of experiments were made at the Nevada test site in May of last year. This was a joint effort by several Government agencies. From this series we learned a great deal about radiation penetration into light residential structures. Protection factors for three types of residential structures are shown in table 2. The ground contributions to reduction factors in table 2 refer to locations below the average window sill level. At greater heights above the floor the ground contribution will be greater due to radiation through windows. The protection factor will be correspondingly decreased.

Another series of experiments was made last December by Technical Operations Inc. to measure penetration into fallout shelters and to extend some of the measurements made in the earlier experiment. These experiments indicated that a basement fallout shelter constructed of 8-inch concrete walls and roof will provide a protection factor between 100 and 250.

Measurements were made recently by Technical Operations, Inc., on the AEC Headquarters Building in Germantown, Md. Since this building has very heavy walls and floors, almost the entire dose is from radiation which enters through the windows. Results from this experiment will provide a valuable check on calculations of protection in large office buildings.

Experiments in structure shielding

May 1958 (References 1 and 17)

Participating agencies:
- Atomic Energy Commission
- National Bureau of Standards
- Oak Ridge National Laboratory
- Office of Civil and Defense Mobilization
- Tracerlab Inc.
- University of California

Structures examined:
- Two-story wood frame house
- Two-story brick veneer house
- One-story wood rambler
- One-story precast concrete house

Radioactive sources: Co^{60} and Cs^{137}.

Scope of measurements: This experiment gave information on dose rates above ground from both roof and ground sources. Data were also obtained in basements for roof sources. Some data were obtained in basements for ground sources but experimental errors were rather large.

November 1958 (Reference 19)

Participating agencies: Technical Operations Inc.

Structures examined: Large deserted Army barracks building.

Radioactive sources Co^{60} and Ir^{192}.

Scope of measurements: This experiment gave information on roof contribution and ground contribution to dose rates on the first, second, and third floor of the barracks.

December 1958 (reference 19)

Participating agencies:
- Atomic Energy Commission
- Office of Civil and Defense Mobilization
- Technical Operations, Inc.

Structures examined:
- Four residential structures
- Command post building with heavy concrete walls
- Basement fallout shelters
- Underground fallout shelter

Radioactive sources: Co^{60} and Ir^{192}

Scope of measurements: This experiment gave additional data below grade in light residential structures, and data in basement and underground fallout shelters.

February 1959 (reference 18)

Participating agencies:
- Atomic Energy Commission
- Office of Civil and Defense Mobilization
- Technical Operations Inc.

Structures examined: AEC Headquarters Building, Germantown, Md.

Radioactive sources: Co^{60} and Ir^{192}.

Scope of measurements: This experiment yielded data for roof and ground sources on a large office building with heavy wall and floor construction. The data are expected to yield information on dose rates due to radiation through windows.

1958 and 1959 (Continuing experiment)

Participating agencies: Chemical Warfare Laboratory, U.S. Army

Structures examined: Concrete blockhouse, 12 feet by 12 feet and 8 feet high, with varying roof and wall thicknesses.

Radioactive sources: Co^{60} and Cs^{137}.

Scope of measurements: Data are being obtained for radioactive sources on the roof and on the ground. The extremely simple shape of the building will allow detailed comparisons with calculations.

III. NATIONAL ACADEMY OF SCIENCES ADVISORY COMMITTEE ON CIVIL DEFENSE, SUBCOMMITTEE ON RADIATION SHIELDING

In the problem of shielding from fallout radiation, as well as in all scientific work, it is important that the theoretical and the experimental work be closely coordinated. With this in mind, the Advisory Committee on Civil Defense of the National Academy of Sciences formed a Subcommittee on Radiation Shielding. This subcommittee is composed of people who are actively engaged in either calculations or experiments. It includes representatives from the Office of Civil and Defense Mobilization, the National Bureau of Standards, Oak Ridge National Laboratory, the Defense Atomic Support Agency, the Naval Radiological Defense Laboratory, Technical Operations, Inc., and the University of California. It was formed last October and has met approximately once every 3 months. This subcommittee also serves in an advisory capacity to OCDM in directing its research efforts on radiation shielding.

TABLE 1.—*Categorization of shelter areas*

Category	Protection factor	Typical examples
A	1,000 or greater	1. OCDM underground shelters. 2. Subbasements of multistory buildings. 3. Underground installations (mines, tunnels, etc.).
B	250 to 1,000	1. OCDM basement fallout shelters (heavy masonry residences). 2. Basements (without exposed walls) of multistory buildings.
C	50 to 250	1. OCDM basement fallout shelters (frame and brick veneer residences). 2. Central areas of basements (with partially exposed walls) of multistory buildings. 3. Central areas of floors near midheight of large multistory buildings with heavy exterior walls and floors.
D	10 to 50	1. Basements (without exposed walls) of small 1- or 2-story buildings. 2. Central areas of floors near midheight of large multistory buildings with light exterior walls and floors.
E	2 to 10	1. Basements (partially exposed) of small 1- or 2-story buildings. 2. Central areas of lower floors in large multistory buildings. 3. Central areas on ground floor in 1- or 2-story buildings with heavy masonry walls.
F	1½ to 2	1. Aboveground areas of low buildings, in general, including residences stores, factories, etc.

TABLE 2.—*Shielding factors in some typical light residential structures* [1]

[Values deduced from experiment]

Structure	Location	Reduction factors [2]			Protection factor [3]
		Roof contribution	Ground contribution	Total	
2 story wood frame house	2d floor center	0.078	0.50	0.58	1.7
	1st floor center	.031	.57	.60	1.7
	Basement center	.015	.028	.043	[4] 23
1 story wood rambler	1st floor center	.10	.54	.64	1.6
2 story brick veneer house	do	.031	.14	.17	[5] 6
	Basement center	.015	.021	.036	[4] 28

[1] Values in this table are from an NBS report, to be published. (Ref. 17.)
[2] Reduction factor is defined as dose rate at the specified location divided by the dose rate outside at 3 feet above the ground.
[3] Protection factor is defined as dose rate at 3 feet above the ground, outside, divided by the dose rate at the specified location.
[4] This factor applies to basements with no exposed walls.
[5] This factor applies only for detector locations below window sill level

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Representative HOLIFIELD. Are there any questions? Congressman Hosmer?

Representative HOSMER. No, sir.

Representative HOLIFIELD. Thank you very much, sir, for your presentation.

The meeting of the committee will be in this room in the morning. It has been previously announced publicly that we will go to the Supreme Court room, but we have been fortunate enough to obtain this larger room so we will have our hearings tomorrow in this room.

Our first witness tomorrow morning will be Mr. Myron Hawkins, of the civil defense research project, University of California. There will be more testimony on the behavior of radioactive deposits. Then there will be a roundtable discussion on the basic properties and effects of radioactive fallout in which Dr. Paul Tompkins, Dr. Terry Triffet, Mr. Myron Hawkins, Mr. Joe Deal, Mr. Charles Shafer, Dr. Lester Machta, and Dr. Ralph Lapp will take part. Following that we will start in on the biological effects, and we have a number of witnesses on the biological effects.

The committee stands adjourned.

(Thereupon at 4:45 p.m., Monday, June 22, 1959, a recess was taken until Tuesday, June 23, 1959, at 10 a.m.)

BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

TUESDAY, JUNE 23, 1959

Congress of the United States,
Special Subcommittee on Radiation,
Joint Committee on Atomic Energy,
Washington, D.C.

The subcommittee met at 10 a.m., pursuant to recess, in room 318, Senate Office Building, Hon. Chet Holifield presiding.

Present: Representatives Holifield, Price, Van Zandt, Hosmer, Westland, Bates, and Senators Anderson and Hickenlooper.

Also present: James T. Ramey, executive director, and George E. Brown, George F. Murphy, Jr., professional staff members; Col. Richard T. Lunger, staff consultant, and Dr. Carey Brewer, special consultant, Joint Committee on Atomic Energy.

Representative Holifield. The committee will be in order. Yesterday we had expert testimony which revealed the fact that more than 20 million buildings would have been demolished or rendered useless for occupancy by the presumed attack weapon. We were also given testimony on the specific behavior of various nuclides. This morning we will conclude the testimony on that portion of the hearing dealing with the basic properties and effects of radioactive fallout with the presentation on the effects of terrain and natural weathering factors on fallout deposits by Mr. Myron B. Hawkins of the civil defense project of the Institute of Engineering Research. Mr. Hawkins has been associated with nuclear energy programs since the early days of the Manhattan project. He was associated with the radioisotope production at Oak Ridge. Before joining the University of California he was for 7 years head of the Technical Developments Branch at NRDL. In this latter capacity his experience was in the field of engineering application of countermeasures against radioactive fallout.

Following Mr. Hawkins' testimony, a roundtable panel composed of Dr. Paul Tompkins, Naval Radiological Research Laboratory, Mr. Joe Deal, Division of Biology and Medicine, AEC, Dr. Terry Triffet, NRDL, Dr. Lester Machta, U.S. Weather Bureau, Mr. Charles Shafer, Office of Civil Defense Mobilization, Dr. Ralph Lapp, an independent physicist, and Mr. Myron Hawkins, civil defense project, University of California will discuss the highlights of the information presented during yesterday's testimony.

Mr. Hawkins, will you please come forward and take the witness stand and proceed with your statement?

STATEMENT OF MYRON HAWKINS,[1] CIVIL DEFENSE RESEARCH PROJECT, UNIVERSITY OF CALIFORNIA

Mr. HAWKINS. Mr. Chairman, gentlemen, I want to thank you for the opportunity of being able to speak for the civil defense research project at these very important hearings. I want to express the regrets of Prof. Ronald W. Shepherd, the head of our project, for not being able to attend. At the present time he is in Paris at a meeting of a NATO Committee on Civil Defense.

I want to apologize also for the lack of preprepared visual aids. We did not have a great deal of time to get them ready, and we have a relatively small organization. I will prepare for the record copies of anything that I put on the blackboard.

The two subjects, effects of terrain and effects of weathering on fallout deposits are subjects about which, for various reasons, we can make only fairly generalized statements. Again, perhaps I should apologize beforehand. There are very good reasons, and perhaps this is as good a time as any to explain them.

There has been very little research directed specifically to finding out the answers on these subjects. There have been some historical measurements. By historical I mean that we have measured what we have encountered in the field and tried to interpret it. Some of this information was mentioned yesterday by the various people who spoke. One of the difficulties is the lack of input information regarding fallout characteristics. Dr. Triffet pointed out yesterday the great lack of information, particularly on the types of fallout that may apply to an attack on the United States. I will mention this in more detail later.

In this matter of effects of terrain and natural weathering, some of the theoretical aspects are pretty well understood but other input characteristics are either not described adequately or are highly variable in character. I will speak first of the effects of terrain.

We can surmise that mountains, hills, valleys, trees, and vegetation of one kind or another will have some influence on the deposition of fallout particles. That is, terrain may affect the area upon which they may land in the very localized environment. We can expect also that surface roughness, either on a very small scale or large scale, may have some effects. This type of information is interesting from a number of standpoints; but because of lack of time, I will not go into it in any detail because it is in the prepared statement.

Once a fallout cloud has stabilized after a detonation, the fallout particles are affected principally by two forces—gravity and that of the wind. If you will excuse me, I believe I will go to the blackboard.

Allow me to digress for one moment. I will speak of a unit called the micron, which refers to the size of the particles; and perhaps it would be well to define it in as easy a way as possible. I think you can judge the dimension of one sixteenth of an inch. It is something we see every day if we use rulers. Perhaps because I am an engineer, I

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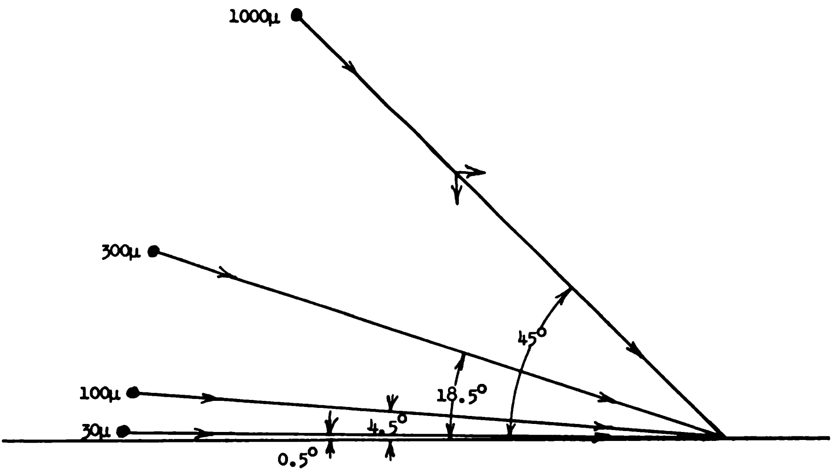
see it every day. If you take that distance of one-sixteenth of an inch, and decrease it by one third, you have the space between your fingers equivalent to roughly 1,000 microns. This is a millimeter. The dimensions we are talking about here are two-thirds of a sixteenth of an inch (i.e., 1,000 microns) roughly a third of that (i.e., 300 microns), a tenth of that (i.e., 100 microns), and so on. In other words, we are dealing with very small pieces of material, as Dr. Triffet mentioned yesterday. As I mentioned before, a fallout particle as it approaches the earth is being forced down by gravity and pushed horizontally by the wind (see fig. I). The trajectory is the resultant of the two. Very large particles in a 15 knot wind fall at about 45°; 300 micron particles at about 18° from the horizontal; 100 micron particles roughly 4.5°, and the 30 micron particles perhaps a half a degree.

Figure I

Trajectory angles for spherical particles (sp. gr. = 3) in 70° F. air at sea level (wind velocity = 15 knots).



The primary reason I pointed this out was that I wanted you to realize how these particles arrive at the earth. Many of them, except those perhaps very close-in to the burst point, are arriving nearly horizontally. In other words, it is not coming straight down.

As was pointed out by some of the people yesterday, and as we all know from our own observations, the wind near the earth is affected by the terrain and the structures there. I should point out that most of my discussion from here on is the result of work of Professor Corcos of our organization, who has been interested in this problem of the effects of micrometeorology on the characteristics of fallout deposition.

I will go very briefly into some of these items and perhaps you will have questions later, or you can get it more thoroughly from the formal statement.

Representative HOLIFIELD. Mr. Hawkins, your intention is to put your formal statement in the record as you have prepared it and to summarize it?

Mr. HAWKINS. Yes, sir; I am digressing from it somewhat, based upon the time available.

Representative HOLIFIELD. You make your statement in your own way. I just wanted to know for the record how to handle it.

Mr. HAWKINS. Yes, sir.

(The statement referred to follows:)

THE EFFECT OF TERRAIN AND NATURAL WEATHERING FACTORS ON FALLOUT DEPOSITS

Statement of Myron B. Hawkins, civil defense research project (Prof. Ronald W. Shephard, faculty investigator), Institute of Engineering Research, University of California, Richmond, Calif: This statement indicates the consensus of the staff of the civil defense research project regarding the current state of knowledge on the subject indicated. The conclusions are based on the work of the project as well as that of many other individuals and organizations. The references at the end of the statement indicate the principal sources of the information contained herein.

TERRAIN FACTORS

The usual practice in predicting fallout patterns is to assume that the surface being contaminated is a uniform infinite flat plane. While this assumption may be needed to reduce the problem to manageable proportons (and is undoubtedly adequate for predictions of fallout on oceans), we know that the land areas of the earth are actually composed of natural features such as mountains, hills, valleys, plains, bodies of water, etc., as well as manmade structures. In addition, much of the earth's surface is covered with many varieties and sizes of vegetation. Consequently, it is important to know to what extent these surface anomalies influence the location of the fallout deposit. The scope of this part of the statement is limited to the effects of natural terrain features on the initial deposition of fallout. Migration of the fallout may occur after contact; this phenomenon will be treated in the second part of the statement.

Information regarding the terrain effects is important from several standpoints:

(*a*) It is important to know to what degree actual fallout intensities may deviate from fallout predictions based on smooth-plane theory as a result of terrain effects. That is, we need to know how much variation in radiation intensity specific terrain features can introduce at locations for which smooth-plane theory would be otherwise adequate.

(*b*) It is also important to know how to interpret a radiation measurement made at a single point in terms of the general radiation intensity in the immediate vicinity of that point. We should know to what extent such a measurement may be affected by an uneven deposition of radiation sources.

(*c*) In planning radiological monitoring and survey operations, information is needed concerning how many monitoring positions are required (and where they should be located, relative to terrain features) to obtain an accurate indication of the overall radiation pattern; that is, to permit accurate estimation of the related radiation intensity at other, unmonitored locations. At our project we are particularly interested in this because we are developing a fallout prediction system that utilizes postdetonation monitoring to correct for various estimating errors (1, 2, 3).

(*d*) When we attempt to calculate the shielding characteristics of buildings or plan for decontamination operation, we need to understand the effectiveness of trees, shrubbery, and nearby terrain irregularities as collectors of fallout and consequently as sources of radiation. Similar information is required for the selection of sites for future construction and for recommending appropriate personnel actions in a fallout field.

Unfortunately, at this time, we cannot provide answers to most of these questions, except in a most qualitative manner. Prof. Gilles Corcos of the civil defense research project has studied some of the theoretical aspects of the problem (4) and we feel that we are developing a basic understanding of it. The

most difficult problems are those associated with applying the theory to specific situations. The applications of theory to generalized environmental conditions in a valid manner is even more difficult. Many of the variables that must be considered in practical applications are not well defined and described. One example of this uncertainty is the characteristics of the fallout material. It is obvious that if we are to predict the behavior of fallout around terrain features accurately, we must be able to describe the fallout material. However, as Dr. Triffett has mentioned, the size of the radioactive particles may vary considerably for different types of detonations (5). For instance, if the detonations are in deep water the particles will generally be small, whereas if the detonations are on sandy soil, a wide variety of sizes will be produced with the mean particle size being larger than that from a sea-water detonation. Intermediate conditions may occur with detonations in harbors or on the surface of clay soils, and we do not know how to predict what sizes may occur. Another variation is related to the "stickiness" which is considerable for some types of fallout particles but negligible for others.

After the period of the initial cloud formation, the particles resulting from the detonation are acted on principally by two forces: gravity and the force of the wind. The following table indicates the approximate angle from the horizontal at which fallout particles approach the surface of the earth.

TABLE I.—*Trajectory angles (in degrees from horizontal) for various size spherical particles (spgr.=3) in 70° F. air at sea level*

[In degrees]

	Particle size, microns			
	30	100	300	1,000
Horizontal wind velocity:				
5 knots	1⅔	13⅓	45	71
15 knots	½	4½	18½	44½
30 knots	¼	2¼	9½	26½

Only for the largest sizes and under very low wind speeds do the particles approach the earth at a steep angle. Otherwise, the angle of approach and contact with the earth is small.

As is well known, the wind patterns near the surface of the earth are modified by terrain features as well as by manmade structures (6). The air flows up, over, and around any obstruction. Small particles tend to follow the path of the air whereas the larger heavier particles tend to continue in their trajectory in spite of changes in the direction of airflow. This effect is, of course, related to inertia and if the change in air direction is gradual, there is a greater tendency for all of the particles to follow the air, although gravitational forces continue to influence the overall resultant trajectory.

Around very small objects, such as twigs and small branches, the changes in air direction are very sudden and even very small particles will impact on the objects. If the obstructions are somewhat larger, say up to the size of large buildings, the changes of air direction are less sudden, and we can expect only the larger particles to be impacted on the obstructions. The smaller particles will follow the air and not contact the obstruction. It should be noted that although a particle impacts on a vertical surface, it will not stay there unless the surface or the particle is "sticky" or the surface has near-horizontal irregularities, or the electrostatic forces are large. Dr. Corcos has summarized the impaction phenomena with some idealized examples:

(*a*) For terrain consisting of horizontal areas and solid vertical cylindrical obstructions about 5 feet in diameter, particles 75 microns and less in diameter will deposit only on horizontal surfaces and will not be impacted on the obstruction, except when the wind velocity exceeds 30 knots. Larger particles will impinge on the obstruction, with the amount of "catch" increasing with particle size.

(*b*) Similarly, if the solid obstruction is 100 feet in diameter, particles up to 350 microns in diameter will bypass the obstruction if the wind has a velocity of 10 knots or less.

Other sudden changes in air direction may occur at the sides, top, and lee side of such obstructions. The effect of these on the deposition pattern is dependent upon the size and shape of the obstruction, the velocity of the air and the size of the particles. As a general conclusion, the size of the downwind area in which deposition irregularities occur is comparable with the dimensions of the obstruction.

If the obstructions to flow are trees or shrubs, some of the air and some of the particles will enter the plant structure rather than pass around it. In this case, the tree will tend to act as a filter, catching the larger particles and perhaps many of the smaller particles. However, since much of the air will pass over and around the tree, we would expect that the fallout deposition downwind would not be greatly reduced by the filtering action of the plant.

The filtering action of trees, however, indicates a second problem (33). Considerable experimental work by Dr. Larson and his associates at USLA (7), as well as other people, has demonstrated that only small particles (i.e., less than 40 to 80 microns) will adhere to foliage unless the particles exhibit adhesive properties themselves. This has been supported also by certain work related to crop dusting (8). Consequently, the larger particles, after they contact leaves and twigs, would drop to the ground under the obstruction. Thus, while the tree itself might not be a relatively strong source of radiation, the ground underneath could be.

When the obstructions are large (i.e., mountains), severe air accelerations are not expected and the particles will generally follow the path of the air. A wind perpendicular to a mountain range extending a considerable length will flow generally up one side of the mountain and down the other and the particles will follow a similar pattern. Theoretical studies by Dr. Corcos show that a particle will land at essentially the same horizontal location regardless of the presence of the mountain. This is easier to understand if one pictures a particle slowly falling through the air while the air moves first upward and then downward; the overall vertical, as well as the horizontal velocities are reduced on the windward side and increased on the lee side. Since the theory propounds that the concentration of fallout per unit of horizontal area remains the same, there would be some small advantage of being on a slope where the actual area is larger than the horizontal area.

If the mountains are isolated peaks rather than long ranges, or if the wind is not perpendicular to the axis of the range, lateral deflections of the low-level winds will result. Since the directional changes will be gradual, the fallout material will tend to follow the air. Such lateral wind deflections may result in deflections of the location of deposition for individual fallout particles. However, if the fallout cloud is large, the individual particles deflected in this manner will be compensated for by other particles and the overall effect will not be great.

Terrain features may have secondary influences. For instance, it is not uncommon for surface winds to run up and down the length of valleys although the upper winds are perpendicular to them (6). This, of course, could divert the fallout patterns in a like matter. In some cases, the wind may show great variations in direction during the night as compared to the day. Such conditions of local wind variations could cause a great diversion of a relatively small section of air When the fallout clouds are large, e.g., in full-scale nuclear war, the relative differences in fallout contamination level might not be great. On the other hand, if the cloud is small, e.g., from the tactical use of small weapons, contamination levels at a specific location could be greatly different from the predicted value.

The terrain, of course, often affects precipitation which may alter the fallout concentration. For instance, the precipitation on the westward side of the Sierra Nevada Mountains exceeds that on the eastern slopes. It follows then that if the fallout occurs during the "rainy season," the precipitation, because of its scavenging action in the air (6, 10), would deposit on the western slope fallout material that would have passed over the mountains and been deposited elsewhere. As far as we know, no one has made a study of this effect.

Dr. Abraham Broido, who is a consultant for our organization, as well as an employee of the U.S. Forest Service, has given considerable study to the influence of mass fires on fallout deposition (11). He has conducted wind-tunnel experiments that indicate that the thermal columns produced by the large-scale fires, either forest or urban, resulting from nuclear detonations may considerably

alter the local fallout patterns. Whether it is feasible to exploit such differences remains to be determined.

Terrain may be important from another standpoint. If the ground is sufficiently rough, the radiations from fallout at a distance must pass through a portion of the ground before they reach the area of interest. A person standing on a flat plane contaminated evenly by fallout receives about half of the radiation dose from the area within about 30 feet. Theoretically, the rougher the ground, the smaller the contribution the fallout deposits at a distance will make to the radiation intensity at a given location. For instance, a person on rough ground may receive half of his radiation dose from an area within about 15 feet (12). The overall reduction that may be attained on the usual unpaved areas appears to be about 30 percent (13). This phenomenon is important to the prediction of radiation intensities in the open and in structures as related to fallout concentration and to the determination of the size of areas to be decontaminated. Although USNRDL and other organizations have considered this problem (14, 15), study and perhaps experiments are still required to validate the theory of the mathematical treatment.

As previously indicate, small obstructions may cause local anomalies in the amount of fallout deposition. However, because much of the radiation dose at a given location does come from fallout sources at distances greater than say 15 feet, the anomalies in radiation intensity will not be so great. The most obvious examples, in a generalized sense, of locations that may receive the minimum radiation intensity are: Caves, or "foxholes," or very small islands, on the tips of narrow peninsulas in large bodies of water, or the base of steep banks along the water. Generally, it does not appear to be very practical to attempt to exploit this phenomenon to any appreciable extent.

In conclusion, we have attempted to indicate what is known of the influence of terrain on the fallout deposition. Our state of knowledge makes these statements qualitative even though the theory of particle deposition and the theories of airflow are fairly well understood. As previously indicated, the principal problems are related to the practical application of theory and lack of certain basic input data. Actually, this work has not had a high priority. As a consequence, we are not able to draw the type of conclusions that we would like. We know that the various aspects of terrain will influence the fallout patterns. Generally speaking, we can consider the problem from two standpoints: When the obstructions are small, say up to about 80 feet, we can expect irregularities in the fallout pattern of a size comparable to the size of obstruction. Very large obstructions, i.e., between 100 feet and a mile in dimension, may cause some irregularities on a larger scale, depending largely on how the gross wind pattern is affected. When the fallout cloud is basically small, the differences between the amount of deposition that occurs and that which would be predicted by the usual theoretical methods may be large. If the fallout cloud is large relative to the size of the terrain feature, the differences will not be so great. However, some weather conditions, e.g., precipitation, high-velocity winds, etc., coupled with the terrain effects will emphasize the differences. Although a more comprehensive understanding of terrain effects is needed in order to develop more accurate technique for the predictions of hazards and planning of operations, we cannot expect the effects to be great enough to provide many natural solutions to the operational problems.

NATURAL WEATHERING

Once radioactive fallout has been deposited on the surface of the earth, there is every reason to expect that the influences of nature will tend to move it from one location to another. This migration may be of the whole fallout particle or merely a fraction of it. Obviously, we are primarily interested in the translocation of the radioactive components. Such migration may be important from several standpoints:

(*a*) It may cause the radiation intensities at a given location to be greater or less than the intensity levels predicted on the basis of decay alone.

(*b*) Migrations of fallout into water supplies could increase the ingestion hazard and the movement of water could carry the fallout material into areas that might be otherwise uncontaminated.

(*c*) Migration into the ground could influence the amount of radioactive material taken up by food crops.

The basic natural forces of prime importance in migration appear to be wind, rain, and waterflow.

All of us are aware of the general phenomena of soil erosion by wind. Dr. W. S. Chepil, of the Agricultural Research Service, has studied this phenomenon extensively (16, 17). Briefly, his conclusions are as follows:

(*a*) If a smooth surface of noncohesive soil is exposed to winds, particles in the size range 50 to 500 microns are highly erosible. Both larger and smaller particles are difficult to erode.

(*b*) If the area is sufficiently large, the erosive action of the 50-500 micron particles will dislodge smaller particles and break up the larger particles by impaction.

(*c*) The larger particles of eroded material will not travel far but will be redeposited generally in the surface depressions throughout the area; whereas the very small particles (i.e., less than 20 microns or so) that are "kicked up" by other particles may form dust clouds that are carried great distances from their source.

(*d*) Erodibility tends to decrease with increase in surface roughness and with the amount of vegetation present. The erosion of soil from a grassy plot is negligible.

(*e*) Only dry soils are moved by the wind.

(*f*) The lowest wind velocity that can produce soil erosion is 9 to 10 miles per hour (measured at a 12-inch height), and under field conditions, erosion usually does not become perceptible until the velocity exceeds 13 miles per hour.

These findings can be applied qualitatively to the erosion of fallout by wind as follows:

(*a*) One would expect the dry fallout to be eroded from tilled fields or fields with sparse vegetation in a manner similar to soil of the same particle size range. Similarly, dry fallout particles on paved areas would be blown to areas where the surface roughness, vegetation, and obstructions trap them more permanently. If the areas are small, however, many of the very small and the very large particles may remain in place.

(*b*) Fallout on areas covered with vegetation will not appreciably be carried off by wind.

These conclusions are supported in general by others (10, 18, 19). Dr. Dunning (20) reports that the maximum radiation intensities from a narrow fallout pattern on the Nevada desert were reduced considerably by the action of strong winds. Such results are to be expected if the fallout path is narrow, e.g., that produced by a very small surface detonation.

The action of rain is much more complex. At the civil defense research project, we have studied this problem in connection with hazards of fallout in water supplies (21, 22). Fallout from a detonation on a land surface tends to separate into three parts upon contact with water: settleable solids (particles larger than 0.1 micron in size), nonsettleable insoluble colloids (particles between 0.001 and 0.1 micron in diameter), and soluble materials. It is primarily important to know the fraction of radioactive material associated with each part. If fallout lands on a body of water, the basic separation takes place rapidly (23). Subsequently, the large particles may settle out but the solubles and colloids tend to follow the water unless some physical action removes them.

Unfortunately, we know very little about how to predict for any given fallout deposit what fraction of the radioactive material is in each of the three parts. The information we do have is meager. It appears, however, that about half of the radioactive material in the fallout from a detonation in deep sea water is of the soluble or colloidal variety (5). If this is the case, it is largely in a form that after deposition would adsorb on soil or vegetation. The close-in fallout from surface and underground detonations in Nevada appears to have less than 2 or 3 percent of the radioactive material in a soluble form (5), although some fallout fractions collected at greater distances from the detonation by Dr. Larson's group have been "soluble" to the extent of 40 percent (7). It has been reported that the long-range fallouts landing on Great Britain is about 50 percent "soluble" (24).

If the detonations occur on or near the surface of clay soils (which are common in the United States), we cannot predict the size distribution or solubility of fallout with any degree of reliability (5). Most of the following dis-

cussion will be based on the action of close-in fallout from detonations on sandy soils. It is probably not typical.

The extent of migration of fallout by the action of rainfall depends upon the portion of the fallout material which will follow the path of the water. Hydrologists indicate that in many cases only a small portion of rainfall reaches a stream by overland or surface flow (25, 26, 27). Generally, the rain soaks into the ground, either to recharge the ground water or to flow underground to a creek or stream. It is normally only during the heaviest rainstorms or late in a rainy season that the rate of rainfall exceeds the infiltration rate and an overland flow occurs (27). The colloidal and soluble portions of the fallout may enter the ground with the water, but it is unlikely that they will travel an appreciable distance (21). Surface flow over vegetated areas will carry the colloids and solubles with it, but even if they escape being absorbed on other material, they represent only a small portion of the close-in fallout material. However, we do not believe that much of the larger particles will be moved by overland flow, since soil erosion is negligible when the surface is protected by grass sod (27). Thus, it appears that because so much of the close-in fallout is insoluble, large reductions of radiation intensity on land areas cannot be expected as a result of rainfall. However, if the fallout is of the more soluble variety one might expect more of it to be moved at least a short distance.

Rainfall on the built-up areas of cities may be very effective in reducing the radiation intensity. Streets, sidewalks, paved areas, etc., are generally impervious, so that the rainfall must flow over these surfaces. Transport of even the large particles is possible if the surfaces are smooth and the slopes steep enough to maintain an adequate flow rate (28). The action of raindrops striking the surfaces and dislodging the fallout particles is also an important factor (29). Unfortunately, we cannot exploit this phenomenon to the fullest because many of the surfaces of a city are very rough and the drainage patterns are such that material may be concentrated and redeposited in places where drainage is poor. It should be noted that if the fallout is of sea water origin, much of the radioactive material would be more firmly attached to surfaces and rainfall would not be as effective in removing it.

The migration of fallout into water supplies may present serious problems (21, 22). As previously indicated, less than 2 or 3 percent of the close-in fallout will be subject to such migration, although larger amounts of the longer range fallout may be so affected. One study, by personnel of the Robert A. Taft Sanitary Engineering Center, has indicated that about 10 percent of the long-range fallout on a watershed enters the water supply (30). We are presently studying the water supply problem at the civil defense research project and hope to come up with some useful recommendations for water supply personnel. It should be pointed out that technically the potable water problem probably can be solved by the use of ion-exchange columns or other techniques to decontaminate the water (31, 32). However, there may be solutions that are much less expensive. The use of contaminated irrigation water in otherwise uncontaminated areas is also a matter of concern.

The influence of rainfall on uptake of fallout by crops has been considered at other hearings and will be discussed here by other witnesses.

In conclusion, we feel that weathering, either by wind or rain, or close-in fallout on nonpaved land surfaces will not have a significant effect on radiation intensities provided the fallout areas are large and the fallout is similar to that produced by the surface detonations in Nevada. In built-up areas where surfaces are smooth and impervious, both wind and rain may be important factors. Rainfall may be more beneficial because it will tend to carry the fallout into sewers, etc., where it no longer contributes to the general radiation field. In fact, we feel that this phenomenon should be exploited through proper design of surface characteristics and drainage patterns. The gradual migration of radioactive material into water supplies, however, may provide a continuing problem.

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Mr. Hawkins. If, for instance, we have an object sitting on the surface of the ground and the wind is blowing, the wind will pass around either side of such an object. The amount of material that is impacted on the front surface is dependent primarily on the size of the particles, the speed of the wind, and the size of the object. If the object itself is a small twig the wind patterns will pass around it like so (fig. II). The wind may be highly turbulent on the lee side. Very small particles tend to follow the airflow closely. A large particle because of its inertia is not going to turn the corner and may be cast out by "centrifugal" force, and be impacted on the surface of such an object. If the objects are very small (in dimension A), say the size of twigs, these changes in wind direction are very sudden and even very small particles may impact a twig.

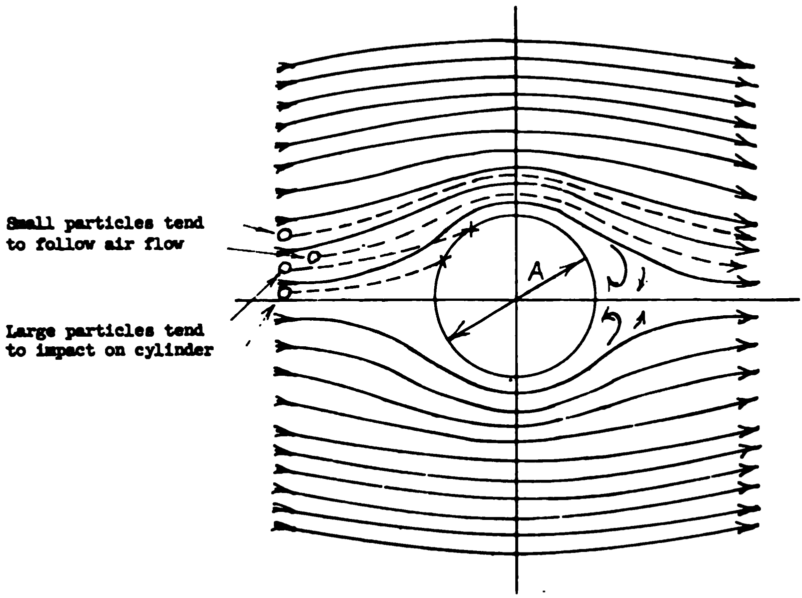

Figure II

Idealized pattern of air flow around a cylindrical object, plan view.

To give you a better picture of the effect of wind on deposition on structures of one kind or another, if the object is around 15 feet in diameter (dimension A) and the wind speed is 30 miles per hour or less, the particles 75 microns or smaller will bypass that object completely. In other words, there will be no impaction on the front surface. Particles larger than 75 microns will impact or impinge on it; and the greater the size of the particles, the greater percentage of them do. If the object is 100 feet in diameter instead of 15, and the wind speed is 10 knots or less, particles up to 350 microns will bypass the object. I use the word "impinge" because this is a place I want to qualify my statement. I want to refer for a moment to Dr. Triffet's diagram which he has permitted me to use (fig. 4, Dr. Triffet's formal statement, p. 71).

These land surface burst particles which are shown in this figure 4 to the left are basically dry sand particles as Dr. Triffet has shown. If these particles strike a surface and the surface is smooth, they will undoubtedly drop to the ground. If the surface is wet, the particles may stick; or if it is made out of bricks—where you have small horizontal projections—or there are window ledges, the material will tend to collect in those places rather than fall to the ground beneath. If the particles are of the type of the water surface burst (fig. 4, p. 71, right side), they will be sticky. Consequently when they impact on the surface, they will stick. From this point further, it is somewhat hard to generalize. In some types of fallout you would have a heavy contamination on vertical surfaces, particularly if the particles are large and sticky. In another condition, there would be very little contamination.

I won't go into what happens on the lee, the two sides or the top of an obstruction, but again particle size, wind velocity, the shape and size of the object, are involved in how much deposition there is on and around such an object.

If the object is a tree or shrub, some air will pass through it and the tree will tend to act as a filter. This has certain implications. I will not go into it beyond that point in my verbal presentation.

If objects, generally speaking, are very large, the wind acceleration that is created is not nearly as great, consequently even large particles will tend to follow the air over a very large obstruction. If we have a mountain range that is perpendicular to the direction of the wind, the air tends to flow up and over such an object (fig. III). A particle traveling in this general direction will be deflected in this manner. Its vertical component will be reduced on the windward side, and increased on the other side. We think it will land in about the same location as it might otherwise.

To put it a different way, under these conditions gross terrain features will not have much effect on the location of the fallout.

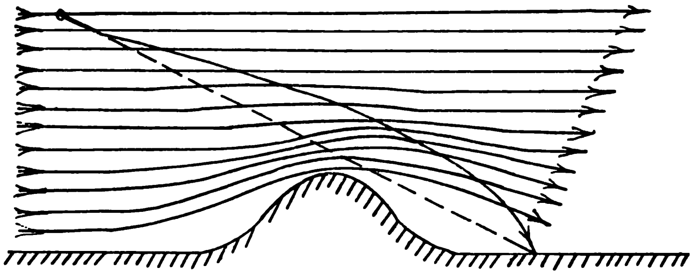

Figure III

Idealized air flow and trajectory of a particle over a long, large obstruction perpendicular to the wind.

Representative HOLIFIELD. This would mean, of course, then, that the people on the offside of the mountain would receive fallout the same as on the near side.

Mr. HAWKINS. Yes, sir. I will make a qualification to that statement.

Representative HOLIFIELD. All scientists always qualify every statement they make, I notice.

Mr. HAWKINS. I am just trying to define the different conditions. Now we are looking down this mountain range, and the wind is approaching at an angle other than perpendicular (fig. IV). The tendency will be for a deflection to one side. If the fallout cloud that is arriving there is large compared to the amount of deflection, the overall fallout pattern may be deflected somewhat. But again the overall effect at any one point is not large. The particle that would have landed here (point A) is now replaced by another one. At the edges of the pattern you will get some deflection. This may be important when you have a narrow fallout pattern from a small weapon. This is also the case when local winds flow perpendicular to the direction of the upper winds. If there are two parallel ridges and the local wind flowing down the valley is perpendicular to the upper winds, the particles can be diverted down the valley when they get into the lower winds. Again for a very large fallout cloud, we do not think this will cause great differences. However, for a small cloud from a small weapon, this could make a prediction very unreliable.

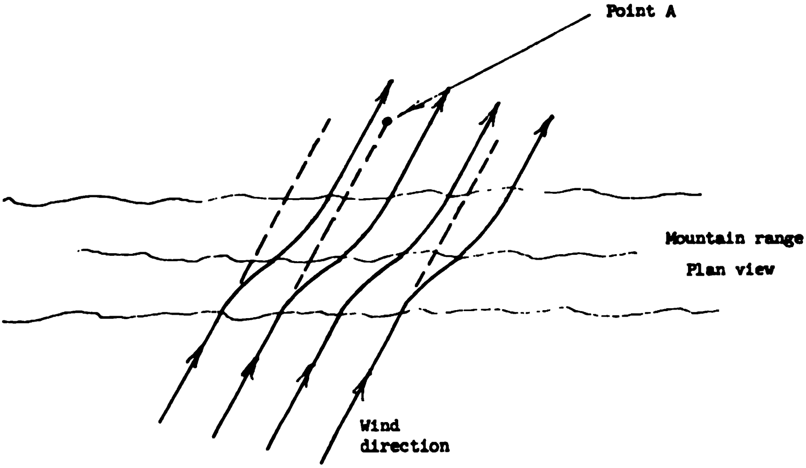

Figure IV

Deflection of wind pattern
by mountain range not perpendicular to wind.

I would like to mention precipitation, although Dr. Machta discussed it yesterday. We believe that there is a relationship between terrain and precipitation, and in some cases there may be a somewhat significant effect. As you probably realize, sir, there is a much greater precipitation on the western slopes of the Sierra Nevada than on the eastern slopes. If the attack comes during our rainy season or during the winter season, it is at least probable that some of the fallout that might have gotten over the mountains to the land in Nevada would be diverted and instead would be deposited on the western slopes. Consequently, we believe the effect of localized precipitation—particularly that which is somewhat predictable because of terrain features—should be investigated in greater detail than we have been able to do.

Dr. Broido, who is a consultant to our project, and also an employee of the U.S. Forest Service, has been concerned with the effects of mass fires on fallout. Dr. Broido has done both theoretical and experimental wind tunnel work on this, and he feels that forest fires or urban fires created by detonations can cause local disturbances of the fallout deposition patterns. Whether we will be able to exploit this remains to be determined.

Representative Holifield. Have you made studies on high altitude bursts, and the effect they might have upon the forest in the fall of the year when the leaves are dry and are more susceptible to forest fires?

Mr. HAWKINS. I assume you mean the detonations that were described as airbursts.

Representative HOLIFIELD. Anywhere from 10,000 up to 40,000 feet.

Mr. HAWKINS. This has been studied extensively by the Forest Service and many other people. I think that AFSWP has been very much interested in it. As you know, the forests have many ignition points, and there is considerable worry about this because of the influence of fires on the water supply problem as well as the destructive effects of fires themselves.

Representative HOLIFIELD. We have the local forest fires in the dry areas in California which are very serious. However, in no instance do I know of where they have extended over a very few percent of the total forest area. It is conceivable and even predictable, is it not, that a high burst, let us say in the area of 10,000 to 20,000 feet high and of a 10 megaton weapon, would create a cone of heat over a very large area, and cause simultaneous combustion in forest areas, as well as the structural area?

Mr. HAWKINS. I do not claim to have followed thermal effects very closely. I would say that there is no doubt but what your statement is correct, sir. I would ask Dr. Shelton to answer in a little more detail.

Representative HOSMER. Mr. Chairman, we do not have that situation in one of our hypotheticals in respect to damage assessment.

Representative HOLIFIELD. That is true. That is not in the hypothetical pattern we have because we visualize ground burst weapons.

Representative HOSMER. That would be a miss on this hypothetical.

Representative HOLIFIELD. On this particular hypothetical, but, as the chairman said, there are many hypotheticals and there might be a mixture of weapons in order to create maximum damage. This is one factor which is not in our hypothetical but which could very well be used by an enemy.

Mr. HAWKINS. Yes, sir. Again as a nonexpert speaking, the thermal effects are very important, could be of great consequence, and perhaps should be considered more than they have been in some cases.

Terrain may be important from the standpoint of shielding. You have undoubtedly heard a certain amount of talk—I know I have—about the infinite uniformly contaminated plane. We have this flat surface (fig. V) that has an even distribution of fallout, and a person standing on it receives radiation from a great distance. I would like to reiterate Dr. Triffet's analogy of a fallout particle being a small light bulb and the gamma radiation being light. Consequently, we have been talking about a deposition of fallout at one location creating radiation intensity at another point. From a smooth plane a person gets half of the total radiation received from a 60-foot diameter area. In other words, if this person is getting 10 roentgens per hour total,

5 of it is coming from this inner area. If the surface is somewhat rough and the contamination level is the same, it is generally accepted that the person gets around 7 roentgens per hour and half of this comes from roughly a 30-foot diameter area. I will not go into this in any greater detail. However, it tends to indicate that we get some protection from the ground being rough and most of the radiation that we are getting comes from sources that are a relatively short distance away from us.

Representative HOSMER. Doctor, at this point one of the witnesses yesterday told us that the irregularity of the terrain made no difference. Were you here yesterday?

Mr. HAWKINS. Yes, sir.

Representative HOSMER. I believe it was Dr. Shelton.

Mr. HAWKINS. I think he was speaking in a broader context from the standpoint of the gross effects of large-scale prediction, the same way that I concluded a few moments ago that terrain effects would not make a great difference on the deposition location. I think he was speaking in that context. I do ont consider this a difference of opinion.

Representative HOSMER. I wanted to clear this up so that we could understand it.

Mr. HAWKINS. Yes, sir. I don't believe I will go into the subject further, except that you can see from the general statement that we do not believe that terrain will normally provide much protection for an individual who is in an exposed location. I will give you a few of the more obvious examples of locations that might provide somewhat greater protection. A small island in the center of a body of water or the end of a peninsula—this is because much of the fallout will settle deeply in the water, and leave the water surface clean as compared to an equivalent land surface. If I had my choice, I would probably dig a foxhole on the island.

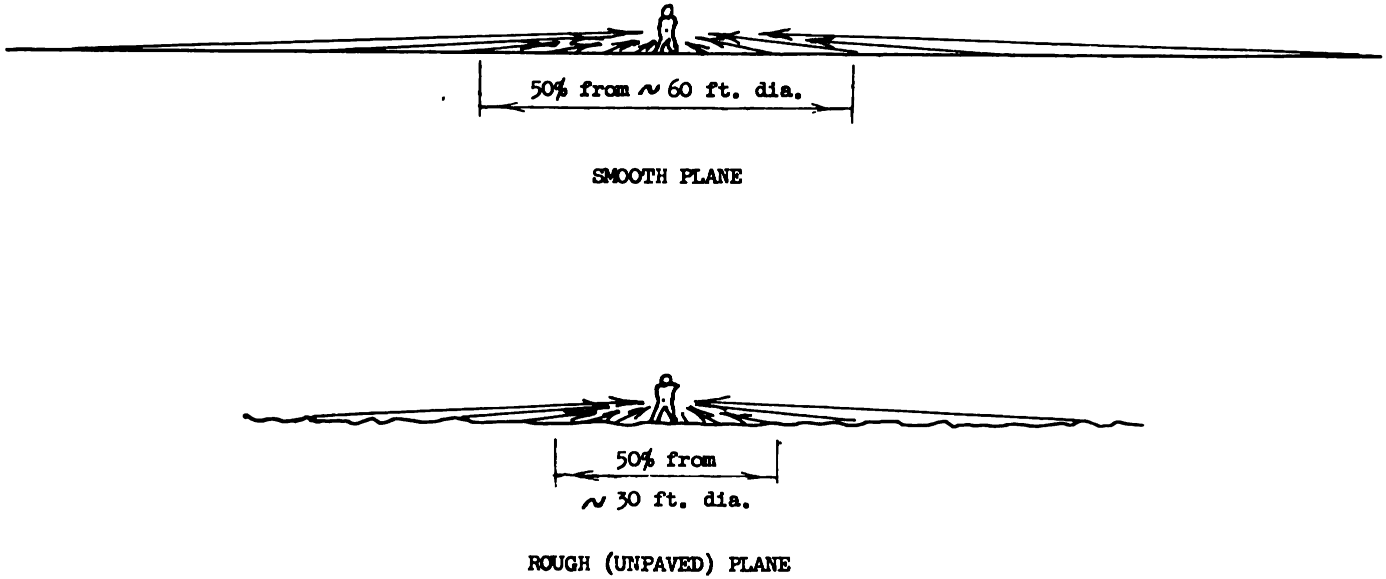

Figure V

Relative contribution of areas to radiation intensity at 3 ft. above surface. (For equal fallout concentrations, radiation intensity above unpaved area is approximately 70 per cent that over the smooth plane.)

The matter of natural weathering is a subject that I would like to take up next. Once fallout has become deposited on the surface of the earth or impacted on vertical objects, we can expect that nature will tend to move it from one location to another. That is, either move the particles as a whole or move some portion of them. Obviously we are interested in whether the radioactive material moves or not. As Dr. Machta mentioned yesterday, the principal natural forces that we expect, and there are others, are rain and wind. Most people are aware of the general phenomenon of soil erosion by wind. Dr. Chepil, of the Agricultural Research Service, has devoted years to the study of soil erosion. We can use a number of his conclusions for estimating the wind erosion of fallout.

Representative HOLIFIELD. I would like for you to proceed until 11. At that time we will have a panel, that is, if you need that much time.

Mr. HAWKINS. I will cut this short: so that if there are any more questions, there won't be any strain.

Representative HOLIFIELD. One thing I hope you will take care of is the relative protection of blast over a mountain. That was brought into our discussion yesterday. The difference between the effects of blast at Nagasaki and Hiroshima, one being in a hill and valley and the other on a plain.

Mr. HAWKINS. I am sorry, sir, I am not competent to discuss that.

Representative HOLIFIELD. We will get that in the panel, then.

Mr. HAWKINS. Yes, sir. On this matter of erosion by wind I will merely say that we are highly dependent on the information Dr. Chepil has collected in terms of dust erosion for our interpretation of what may happen to dry fallout particles. I will go over some of his conclusions rapidly.

The lowest wind velocity at which soil erosion becomes perceptible is about 13 miles an hour. Particles of a size of 50 to 500 microns—which are important from our standpoint—tend to be eroded, but they do not appear to travel very far. They tend to be redeposited within the same general field or area. We can expect dry fallout to be eroded much the same way as this material. However, the conclusion is limited by the condition that the field must be smooth and have very little vegetation on it. If the surface is rough and there is lots of vegetation, it is doubtful in my mind that the fallout particle will be moved. There have been some observations of fallout moving. Dr. Dunning has mentioned one, reiterated by Dr. Machta, of a small fallout pattern decreasing considerably in intensity in Nevada. This is exactly what you would expect in a desert country and when you have a narrow pattern. Under these conditions much of this material can be moved a short distance so that the peak radiation intensity is decreased considerably. If the pattern is large, we don't expect much overall reduction in intensity.

The action of rain is much more complex. Fallout when it contacts water tends to dissociate into three phases. One part consists of particles that are solid, essentially insoluble, and of a size that allows them to settle to the bottom of the water fairly rapidly. Another portion is the colloidal material—insoluble particles of an extremely small diameter that tend to remain in suspension in the

water. This is the turbidity you see in the water that you get out of your faucet at times. Then there are soluble portions which, we might say, are essentially individual atoms that tend to remain in suspension also. One of our great difficulties in predicting a more quantitative sense what fallout is going to do when it is affected by rainfall is the fact that we do not have much information on the fallout properties.

Let me go back for a moment to Dr. Triffet's very useful chart (fig. 4, p. 71). He showed typical land surface fallout particles in these two diagrams. These are basically large insoluble particles that have a number of other particles attached—sometimes loosely, sometimes tightly—to the surface. We find that when these particles are immersed in water many of the small particles come loose from the large particles and are separated from it. The amount of radioactivity in the very small particles, from a land surface burst, is about 1 to 3 percent of the total activity. This value varies from detonation to detonation. Dr. Triffet indicates in his paper that the upper limit is around 3 percent of the total radioactive material. We also may encounter the water surface burst particles. About half the radioactive material is in settleable solids. The other half of the material is present as colloids and soluble material that will tend to remain suspended in the water phase.

Representative HOLIFIELD. Would you hazard an opinion on the difference between a bomb burst in a salt water harbor and one burst on the city nearby, as far as local precipitation of fallout is concerned? I am thinking of the induced radiation of the sodium and salt elements in the water and the fact that it is heavier because of the water particles and would tend to fall quicker than if it were airborne dust.

Mr. HAWKINS. I hate to say that I am not an expert again, because sooner or later you will find out that I am not an expert on anything. I think I do know a little about this so that I can make some generalized statements. This has not been brought out. Generally such particles are considerably smaller in size than the land surface particles. The total number of these essentially represent the total crater material, if you follow me. In other words, in producing the basic fallout material, much of the crater material is broken up into particles like the basic land surface fallout particles (fig. 4, Triffet). In a water surface burst the whole crater is broken up, but you lose in the overall process perhaps 95 percent of the water in the particles. Consequently the total mass of all of these water surface fallout particles may represent only 5 or 10 percent of the total mass of the crater. It turns out that the size of the water burst fallout are generally considerably smaller than those of the land surface burst. This has effect on where they are deposited and how far they travel, et cetera.

Does that answer your question, sir?

Representative HOLIFIELD. Yes.

Representative HOSMER. Let me get this straight. You say in the case of a water burst, since you have smaller particles, they are more likely to stay aloft longer, and thereby be dispersed over a wider area.

Mr. HAWKINS. Yes, sir.

Representative HOSMER. The fallout, when it does fall out, is of less intensity at any particular place, because it is spread over a larger area, whereas your land burst being spread over a smaller area would tend to give a greater amount of radioactivity.

Mr. HAWKINS. Yes, sir.

Representative HOLIFIELD. I was at Bikini in 1946 when the underwater shot was exploded in the lagoon there. We had something like 76 ships spread around in the lagoon over a circumference or radius, rather, of about a mile. Of those 76 ships, I think there ware about 73 that were contaminated, some of them quite heavily. It was generally assumed at that time that it was the downfall of spray and particles that came out of the water that stuck to the metal of the ship wood, and so forth, which caused a great deal of the radioactivity on those ships. I would assume that if a bomb were exploded in a harbor, where the wind was going inland over the city, that you would have the same situation on your steel, concrete, and buildings. In fact, on the surface of the whole city.

Mr. HAWKINS. This is very true. The degree with which material sticks to the surface is something I want to briefly mention later. This was true at Bikini and other places. You would expect a certain amount of rainout of large particles of four to five times the thousand micron diameter. They tend to fall very steeply. Much of the fallout would be of a very small particle size, and would cover larger areas, and take a longer period of time to arrive.

I should mention one other type of fallout because most of the literature that we have, done by people outside of the Government, is based on this type of material. It is the long-range and the intermediate fallout, which appears to be primarily a series of the very small particles, which aglomerate or adsorb together and tend to travel great distances. Generally speaking, it appears that these small particles arriving at intermediate or long-range distances have about 50 percent of the activity in the soluble state, in the definition that we are using.

I can't extrapolate these conditions to the type of fallout that we might expect in case of an attack. I will basically try to speak of the Nevada land surface type of fallout, which is probably not typical of what we may encounter. When rain falls on fallout lying on the ground, the water wets the particles and disassociates it, as I said, into these different fractions. Hydrologists tell us that in most conditions there is not too much above-surface runoff on the land surfaces. In other words, when the rain hits the ground it tends to infiltrate into the ground and travel to either the ground water reservoirs or to streams. They also tell me this is what happens when snow melts in the mountains. There is very little overland flow; most of the water goes down into the ground below the surface. We can expect this underground infiltration to filter out the particles which contain 97 or a greater percentage of the radioactive material.

Some of the very fine particles will tend to follow the water, but there is every reason to believe that much of this will be held up in the upper surface of the ground.

Representative HOSMER. In terms of your salts, they would be mostly filtered out.

Mr. HAWKINS. Yes.

Representative HOSMER. How about the colloidals; will they be filtered?

Mr. HAWKINS. As you will probably hear from later testimony, the soil has a great effect on how far these materials travel and what percentage will pass through.

Representative HOSMER. Your material in solution will pass through?

Mr. HAWKINS. Not necessarily. It tends to adsorb. Again there will probably be more testimony specifically in connection with strontium and how deep it may go into the ground.

Representative HOSMER. The 3 percent that does get through would be of the soluble nature, I presume.

Mr. HAWKINS. In the soluble and colloidal form in the term we are using. This is not saying that 3 percent will travel all the way with the water. Usually, it will be much less than that. I will not elaborate on that particular point, except to indicate that, as you know, in the buildup areas of the cities there are a great many hard and smooth surfaces: Streets, sidewalks, and roofs of impervious construction. The rain obviously does not enter the surface in the same way as it does on an earth surface. Instead, it would tend to run across the surface. From experimental work we have done at NRDL, plus other observations, we know that under the right conditions the fallout material, large particles and small, will be transported away from the point of deposition. Actually the effect of rainfall itself is a very important action which tends to dislodge particles that would otherwise not be dislodged. Unfortunately, at the present time we cannot exploit this phenomenon in the city to the fullest extent because many of the surfaces are rough and drainage patterns are poor. We end up with water being diverted into drainage ditches where the fallout material will tend to collect. If the fallout is of sea water origin, we expect it to be attached much more tenaciously to the surfaces it contacts; and we would not expect as much of it to be removed by rainfall as is the dry material.

We have been interested in this problem from the aspect of migration of fallout into the water supplies, working under an OCDM contract. I will not go into that except to indicate that we hope to have some useful recommendations for water supply people before too long.

There are other problems, such as the use of contaminated irrigation water in otherwise uncontaminated areas. This problem undoubtedly should be studied further.

In conclusion, we feel that weathering of close-in fallout on nonpaved surfaces will not be of great consequence. The fallout will tend to remain where it lands, providing the material is similar to that I have described, the Nevada land surface type. In built-up areas where the surfaces are smooth and impervious, we believe wind and rain may be important. Rainfall is particularly so, because much of the fallout may be carried into sewers where it will not contribute to the general radiation intensity. In fact, we go a little further and say that we feel that the rainfall decontamination phenomena should be exploited through change of design characteristics of surface materials of building and streets, and with more emphasis on the proper slopes and surfaces of drainage areas.

I think that is all, sir.

Representative HOLIFIELD. Thank you. Congressman Bates.

Representative BATES. Mr. Hawkins, when I walked in here you were making a statement that appeared to be in conflict with what Dr. Shelton stated yesterday in answer to the inquiry of Mr. Hosmer. You indicated that Dr. Shelton was talking more generally, and that the effect of terrain was negligible because it followed gravity and except for the small effect that the wind would have it would come down vertically.

I presume because it is so high, regardless of the mountain, it would come down in a vertical path. What was the specific point you were trying to make that appeared to be in conflict?

Mr. HAWKINS. I think I understand your question. What I was trying to say was that I think the point that was being made by Dr. Shelton—was this specifically in terms of blast or fallout?

Representative BATES. I presume it was fallout. Answer it on fallout.

Mr. HAWKINS. All right. He was talking in terms, I believe, of whether terrain effects would cause large areas to be relatively uncontaminated as compared to other nearby areas within miles of distance, or of whether the factors in radiation dosage would be different from one place to another because of these terrain effects. In that context, he was saying it would have no effect. In the same context, I agree entirely with him. I was talking about relatively minor differences. The difference between 7 and 10; shall we say?

Representative BATES. Because of the effect of terrain?

Mr. HAWKINS. Yes, sir; surface roughness.

Representative BATES. In other words, there would be a negligible difference at best.

Mr. HAWKINS. Sometimes when you take a lot of those so-called negligible differences and add them together, you can get an overall effect that is important. I would hate to call the difference between 7 and 10 negligible in all context of application.

Representative BATES. What if you have real high winds? What effect would that have? You indicated a 15-knot wind would change about 30°.

Mr. HAWKINS. A higher velocity surface wind will cause more small particles to contact obstructions in their way. In a gross way, it will cause the material to travel further at the upper altitudes, but will probably cause more deposition on vertical obstructions that are in the path of the wind.

Representative BATES. Essentially, living on the other side of the mountain will not provide much protection.

Mr. HAWKINS. Not unless there are certain weather conditions as I mentioned, such as precipitation. These are specific cases.

Representative HOLIFIELD. Thank you very much, Mr. Hawkins. We will have Mr. Hawkins on our panel. However, before we open our panel discussions, I would like to place in the record a paper by Sanford Baum, of the U.S. Naval Radiological Defense Laboratory.

(The document referred to is as follows:)

Basic Properties and Effects of Radioactive Fallout

FACTORS MODIFYING THE BEHAVIOR OF DEPOSITED CONTAMINANTS

(By Sanford Baum,[1] U.S. Naval Radiological Defense Laboratory)

Estimates of the radiological hazard caused by the fallout from megaton-range weapons are usually obtained either from measurements carried out in the Pacific or by the application of fallout prediction methods. In general, neither of these sources involves direct measurement of fallout which is actually deposited on a land surface. In the case of measurements from the Pacific area, most of the fallout is deposited in the ocean. It is necessary to reconstruct, from measurements of the activity left near the ocean surface, the radiation contours which would have resulted had the same deposition occurred over land. Descriptions of the hazard produced by megaton weapons must contain an assumption about the land surfaces over which fallout is expected to occur. The assumption most frequently made is that the fallout producing the hazard in a given locality is uniformly distributed over an infinitely large plane. Occasionally, this assumption is modified to take the roughness of the terrain into account. A second assumption is that, once the fallout is deposited on the plane, it remains fixed and the only changes in radiation intensity are due to radioactive decay.

When potential targets in the United States are considered, neither of these assumptions is necessarily justified. The targets contain both natural and man-made objects which obviously depart from the conditions of the first assumption. Wind, rain, or snow can either move the deposited contaminant or cover it with inert material such as snow or sand. It is recognized that all of these factors can modify the predicted degree of hazard.

The effect of weather on the deposited contaminant has been discussed by Machta and Nagler (1). Fallout particles in the atmosphere may be trapped in rain or snow. Once they reach the ground they can be washed into the ground or carried away by runoff. The latter effect is more important usually, because, once the airspaces in the ground are filled with water, most of the additional water will run off into streams, carrying along more of the radioactive particles.

Fallout deposited in the dry form can be affected by rain or snow. Significant transport will result when raindrops dislodge particles in strong winds or on slopes with as little as 10-percent grade. The winds can move the particles directly. The primary factor here is size of the fallout particle. Particles whose diameters range from 50 to 500 microns are the most easily moved. In areas of significant hazard particles in this range are responsible for most of the radiation (2). In general, the movement of these particles will result in a net lowering in the regions of high intensity and some extension of the fringe areas.

There is little quantitative information on these topics. Qualitative evidence which, in the main, supports the above conclusions have been described by Strope (3). The problem is complicated because of the variability in the meteorological parameters. In general, the effect of weather is to reduce the predicated intensities.

Experiments to determine the change in hazard caused by gross differences in natural terrain have been performed. Equal amounts of a radioactive isotope were placed in an identical manner on equal areas with varying degrees of roughness. The roughness ranged from that of a smooth concrete slab to that of a wooded hilly field. It was found that the hazard decreased with increasing roughness. At the standard height of 3 feet, the radiation from the roughest surface was two-thirds that of the smoothest. Differences caused by varying surfaces of measurement tend to disappear with increasing height. Comparisons have been made between a fallout-contaminated Nevada area and computed results based on the flat plane assumption (5). It was found that in the real case, the deposited fallout behaves as if it were uniformly mixed to some shallow depth, of the order of an inch, in the soil. This implies that the flat plane value will be too high (4, 5, 6). Another consequence of this difference is that in an

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area partially free of fallout, the radiation intensity first increases and then decreases as the height of measurement over the cleared area increases. The latter consequence is of importance in considering the shelter afforded by multistory buildings. Comparisons between calculated values obtained on the basis of the infinite plane and observed radiation intensities were possible for one event and location in the Pacific (7). It was found that the ratio of observed to calculated intensities varied with time. Ratios of 0.45, 0.66, and 0.56 were found at 11.2, 100 to 200, and 370 to 1,000 hours, respectively.

The role of vegetation and trees, which could in effect elevate some of the fallout above the surrounding ground level, has been examined by Baum (8). It was concluded that the amount of radiation contributed by the fallout attached to vegetation or trees would be small when compared to that emanating from the ground. This situation was considered by Lindberg (9), whose work (10, 11) in Nevada, provided much of the data used by Baum. Lindberg also concluded that the contribution from contaminated plants would be small. It was recognized by all concerned that rather large extrapolations were required to reach the conclusion and that more direct evidence was desirable.

When the fallout occurs over a community, a number of departures from the infinite plane case are encountered. Part of the fallout that would have been deposited on the ground is now resting on roofs. This has the effect of reducing the predicted intensity by (1) placing the fallout a greater distance away from the standard measuring point near the ground, and (2) interposing material between the fallout and the measuring point. Walls interpose material between the measuring point and fallout deposited on streets and unpaved areas. The reductions achieved are dependent on the dimensions and composition of the structures and in their placement relative to one another. Methods for predicting these reductions have been published (12, 13, 14). An indication of the effect of adjacent structures, in heavily built-up urban areas, is given by the following numbers. The values listed are the reductions in intensity in an area adjacent to one or more streets.

Number of adjacent streets	1	2	3	4
Reduction of predicted intensity	0.2	0.3	0.4	0.5

Application of these numbers should be made with discretion and only after reference to the original source (12). This requirement holds for all such numbers.

In the presence of even moderate winds, vertical surfaces such as walls introduce an additional perturbation. Under these conditions more particles are, in essence, flowing toward the walls than are falling to the ground. In spite of this fact, it has been observed that the ratio of horizontal to vertical contamination may vary between 5 to 1 and 300 to 1 (3). Either the particles strike the vertical surfaces and then fall to the ground at its foot, or because of airstream effects, the particles flow around the vertical surfaces. Comparisons have been made (3) between the contamination found on horizontal surfaces at the head and foot of vertical surfaces. No significant differences were found. The investigation also found that there were no differences between the front and back sides of vertically oriented surfaces. These observations can be explained on the basis of flow around the surfaces. A theoretical study of airstream phenomena has been published (15). It predicts that 75-micron particles will deposit only on horizontal surfaces and that inhomogeneites will occur rarely and over small areas. Inhomogeneites in deposition are expected to occur with particles around the 350-micron size. The most common effect will be a decrease in deposition on the roof and lee of large buildings. No upper limit can be set on the maximum concentration which may be found under adverse circumstances. It has been reported that the best available estimate of the range of significant particle sizes in areas of hazardous fallout is 50 to 400 microns (2).

Most of the experimental evidence quoted was obtained under the conditions that exist at the test sites. Extrapolation to U.S. targets involves the deposition of a possibly different contaminant into an environment very unlike that encountered at the sites. Hopefully, the difficulties inherent in the latter circumstance can be surmounted by investigations now underway at NRDL or elsewhere. Lack of knowledge concerning the basics of the fallout formation process, precludes any definitive statement about the probable nature of the fallout from U.S. targets. Consequently the extrapolation cannot be performed with confidence. Within this limitation, it has been found that the overall effects of terrain and weather reduce the hazard predicted on the basis of current assumptions.

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Representative HOLIFIELD. At this time I will ask the panel members to come forward.

ROUND TABLE PANEL DISCUSSION ON THE BASIC PROPERTIES AND EFFECTS OF RADIOACTIVE FALLOUT

Participants: Dr. Paul Tompkins, Naval Radiological Defense Laboratory; Dr. Terry Triffet, Naval Radiological Defense Laboratory; Mr. Myron Hawkins, civil defense research project, University of California; Mr. Charles Shafer, Office of Civil Defense Mobilization; Dr. Lester Machta, U.S. Weather Bureau; Mr. L. Joe Deal, Division of Biology and Medicine, AEC; and Dr. Ralph Lapp, independent physicist.

Representative HOLIFIELD. The panel has been convened in an effort to clarify and consolidate an understanding of the specific technical points upon which an agreement exists and a clarification of those areas in which disagreement is apparent. In line with the committee's objective in bringing before the public, in an understandable

form, the technical facts bearing upon the consequences of nuclear war, the committee is interested in considering three principal categories of information. These are:

1. New information in relationship to previous information.
2. Clarification of the meaning with which these technical facts should be associated in order to minimize misconceptions about the consequences of nuclear war.
3. Highlight significant differences which must be understood in relation to wartime in contrast to peacetime standards of application.

I am going to ask our consultant from the Naval Radiological Laboratory, Dr. Tompkins, if he can suggest an outline upon which we can base this discussion. I want it understood, of course, that all members of the committee will be free to ask any question they want to of any member of the panel or of the whole group. Dr. Tompkins.

Dr. Tompkins. Thank you, Mr. Holifield.

I think I would like to suggest as an outline, since there has been a considerable quantity of new information presented—that is, new from the point of view that it differs either in terms of numbers or in terms of the type of previous information—I think perhaps we have considered the relative characteristics of this particular attack along with some of the others, and along with the other effects which are not predominant in this attack in order to get a perspective. There has been new information developed on some of these interrelations which I would like to bring out.

The problem of the magnitude of the radiation associated with fallout, I think, has developed several new points of information which should be clarified, although most of these have been mentioned at various places in the testimony. I refer specifically to the dose rate relationships in fallout areas and patterns, times of arrival, and things of this nature, as contrasted with the information that was presented in 1957.

I think we should discuss briefly, at least, the significance of fractionation that Dr. Triffet mentioned.

Representative Price. I wonder if the doctor would state specifically right at this point, so we will have it in context, the new information that has been brought out, and then proceed to clarify it.

Dr. Tompkins. The new information within the definition I gave is that the present information clarifies the greater significance of thermal effects under some conditions of detonation in comparison to the emphasis that has been placed on it in previous discussions. Scientifically, there is no difference in the relative effects of blast, thermal and radiation effects. However, weapon technology has advanced 5 years. One is increasingly concerned with this type of effect, and I think its existence should be noted. That is one item.

The second is the relationship between the actual behavior of the fission products and their decay characteristics versus the deductions that one would make from the information in the current official document on the effects of nuclear weapons. Specifically, the magnitude of the gamma radiation threat, which is the killer at short times, is underestimated by a factor of about 2 in this document, which would lead to some errors on the effect of weapon yield, magnitude of the threat, and a few other factors.

Representative HOLIFIELD. I certainly want to explore that. As I understand, yesterday the OCDM used the old t minus 1.2 factor of decay, and we do have later information on that subject. I don't know a better way to start this discussion off than to throw this right on the table at this time.

Representative PRICE. Will you complete your statement about the new information that has developed?

Dr. TOMPKINS. The other thing I wanted to mention is what happens at the other end of the curve. If you take the implication of the t minus 1.2 law with respect to the actual behavior of the fission products, you come to the conclusion that the long-range problem is much, much worse, than it really is. Information developed specifically in the past 2 years shows that the rate at which the gamma radiation threat diminishes with time is faster than predicted. This has a very significant bearing on our ideas as to how serious it is. In other words, the nature of the threat is overestimated rather significantly.

These two points I think constitute two new areas of information insofar as any data presented either in the 1957 hearings or previously are concerned. This is not scientifically new. I want to draw that distinction. I am not necessarily talking of scientifically new information.

Representative HOLIFIELD. I want to direct to Mr. Shafer, at this

Dr. TOMPKINS. It is new in the application and the implications are different. I am going to stop with that. There are minor ones but they are more of a scientific nature.

Representative HOLIFIELD. I want to direct to Dr. Shafer, at this time, a question in regard to your testimony yesterday, wherein you stated that you used the old values for radiation intensity associated with fallout. I believe this means you assumed that the fission products produced by a 1-kiloton explosion, if uniformly spread over 1 square mile, produced 1,250 roentgens per hour at H plus 1 hour. The new data yelds a value of 3,600 roentgens per hour at H plus 1 hour. That is a factor of 2.7, I believe—a factor of greater degree of intensity and hazard, as I understand it. If this is correct, the thing I would like to ask you is why did you not use the new factor of decay rate?

Mr. SHAFER. May I refer to my testimony of yesterday before I answer the specific question? If you will recall, Mr. Chairman, on the chart which we used for discussion of the radiation doses we showed the maps for D-plus-2-days and D-plus-2-weeks. On the map for D-plus-2-weeks, the most severe radiation dose during the first 2 weeks was about 10,000 roentgens. This is the outside, unsheltered, accumulated dose during the first 2-week period. If these data were underestimated by a factor of two or three, this would imply that the radiation dose during the first 2 weeks in these most intense zones would not be 10,000 roentgens, but rather 20,000, or possibly 30,000 roentgens. If you will recall, shieldingwise, protectionwise, we in OCDM advocate this 8-inch concrete block basement shelter, which would reduce the radiation dose to 1/250. If the data we presented yesterday were correct this would mean the people in these most intense zones would be exposed to about 40 roentgens during the first 2 weeks in this type of shelter. If we were off by a factor of two, it would mean they would be exposed to 80 roentgens. If it was as bad as a factor of

three, they would be exposed to 120 roentgens. Actually the shielding afforded by this degree of protection would be adequate even in these extreme cases. Quoting from the Effects of Nuclear Weapons, a whole body radiation exposure of 80 to 120 roentgens over a short period of time will result in nausea for about 1 day in 5 to 10 percent of the people exposed, with no serious disability and no fatalities.

This would mean that the people in the worst condition, even if our dose computations of yesterday were off by a factor of three, would still have sufficient protection. This is in the worst condition, and we have adequately planned for it in OCDM.

Most of the areas of the country would be much less severely affected than the 120-roentgen exposure areas. Actually by 1950 census there were some 96 million people in the United States who did not live in or near a likely target area. So what this means is that even if the enemy were able to deliver such a magnitude of attack as to completely obliterate all likely targets with blast and thermal effects, there would still be some 96 million, possibly more, people surviving, if they had this degree of protection.

As to the reason why did we use t to the minus 1.2, the Effects of Nuclear Weapons is still considered an accepted and authoritative source and we based our computations on it, sir. However, in our civil defense planning, we recognize its limitations.

Representative Holifield. This is 3 years old. The nuclear weapons handbook was put out in June 1957. In view of the fact that there has been testimony before this particular committee in 1959 which casts serious question upon the original data, it does seem to me that you would have used the later data. In view of that fact this application would be all down the line without regard to distance. In other words, if it is three times as intense at 1 mile, it would be three times, roughly, as intense at 20 miles. So you would have a much higher factor of dose and a longer factor of exposure.

Mr. Shafer. There is one thing I would like to point out, sir. There is uncertainly with regard to the newer data which Dr. Tompkins reported. The data in the Effects of Nuclear Weapons probably represents the minimum. The data from Dr. Tompkins probably represents the maximum. Something in between perhaps is more realistic. So had we accepted the data about which Dr. Lapp and Dr. Tompkins have reported we would be accepting the upper limit, and I think we would be subject to as much uncertainty, if not more so, sir, and criticized for overestimating or magnifying the fallout problem.

Representative Holifield. Let us hear from Dr. Tompkins on that.

Dr. Tompkins. Essentially what Mr. Shafer says is correct, Mr. Holifield. I would like to make this comment. With regard to the results of this particular exercise, I do not think that the use of t to the minus 1.2 law is going to throw the results of these particular computations very seriously one way or another. This is not the reason I bring it up. I bring up this new information because the official data under which nearly all of the people in this country are deriving their ideas as to the nature of the threat, and even reaching decisions in their own minds with respect to whether protection is even necessary, are based upon the results of this particular document. I am not trying to criticize the OCDM testimony in this case,

but I do want to call attention to the fact that due to the induced activities, due to the earlier decays, and due to better knowledge of the composition of the fission debris, the basic information on which we have been operating is not strictly correct in this region.

Representative HOLIFIELD. I want to say that maybe the AEC is at fault for not bringing out a new weapons handbook. Maybe the Congress is at fault for not bringing it out. I don't know. But as long as this information is available, I would like to have the other members of the panel express their opinions as to whether the later information is worthy of consideration in the planning of such an assumption as this, or whether we are justified in holding to the old data which we now know is 3 years old. I would like to have some expression from Dr. Machta on that.

Dr. MACHTA. Since we in the Weather Bureau were primarily responsible for preparing the OCDM local fallout patterns, I would like to justify what we did. We did not use in any way either the conversion in the Effects of Nuclear Weapons or the NRDL conversion, because it was unnecessary to do so.

In the Pacific we detonated a bomb of X megatons. We observed the distribution of fallout as dose rate readings. Then we scaled this pattern to other megaton yields. In doing this we did not have to employ the conversion in question at all. The fallout isolines are essentially correct.

Representative HOLIFIELD. Dr. Triffet, do you wish to comment on that?

Dr. TRIFFET. As I understand what Dr. Machta said, you used a burst at one yield and scaled this to other yields.

Dr. MACHTA. We didn't do it. This is what the AFSWP (DASA) model does.

Dr. TRIFFET. I would have certain serious questions to raise about the application of this model in this case.

Dr. MACHTA. We do, too.

Representative HOLIFIELD. This is the place to raise it.

Dr. TRIFFET. The model in general is based on simplified assumptions and on certain scaling rules which, in view of the irregularity of patterns, variability of the wind, uncertainties with regard to particle size, are questionable.

Representative HOLIFIELD. Would you agree with that, Dr. Machta?

Dr. MACHTA. Yes. It is for this reason we pointed out that the patterns in fact will be quite irregular and the AFSWP model is overidealized.

Representative HOLIFIELD. That was another point that was involved in the testimony which we hope to get to.

Dr. Lapp, would you care to comment on this question?

Dr. LAPP. My only comment is that I started out to more or less analyze the problem last summer. I took as the bible the "Effects of Nuclear Weapons" and proceeded to calculate what the radiation dosage would be assuming that the data they gave were correct. Then I chanced upon the reference to a U.S. Naval Radiological Defense Laboratory report. It took me some 7 months to get this document. It was unclassified, but apparently the economy of the Government is such that the person outside of the Government cannot

get this report. However, I did manage to get it on loan. By that time I had independently calculated the same data, although in much more approximate form, and I had serious reservations about the validity of the "Effects of Nuclear Weapons." This came as quite a surprise to me, but the biggest surprise of all came when I looked at the rate of decay of this radioactive material. Previously the $t^{-1.2}$ law has been the rule that has been spelled out many times. It has been my impression that if one follows this law in planning a defense of this country, one is almost committing himself to death, because the long term effects of gamma radiation predicted by the $t^{-1.2}$ law are extremely severe. However, one may analyze the data based upon new information of a theoretical nature with respect to the rate of decay of the fission products—I might point out at this point that the original data on which the $t^{-1.2}$ law are based goes back to 1942, to data of Dr. Wigner, and this law has been used ever since 1943. It was never meant, I think, to apply to a long period of time, but it has been used as an approximation. To me thes ignificant thing is not so much that the hazard is greater in the first few weeks by a factor of, I assume, around 2.

Representative HOLIFIELD. Just a minute. The new data show as I understand it about a 2.7.

Dr. LAPP. Yes.

Representative HOLIFIELD. For your assumptions you are cutting in between and taking a factor of 2 rather than almost a factor of 3.

Dr. LAPP. I didn't wish to be accused of being an extremist.

Representative HOLIFIELD. You are a middle-of-the-roader; is that it?

Dr. LAPP. I think that would be a new definition. I was quite surprised to find that if one calculates the intensity of the radioactive material, and for this purpose I assumed a kind of standard that you take the fission products associated with 1 kiloton explosion and deposit them uniformly on a flat impermeable plane—this is a billiard table calculation—if you put them on the billiard table, 1 square mile, then you will get a radiation intensity from this. Then you follow the radiation intensity for a period of weeks, months, and years. When you do that, you find at the end—I think the best way is not to talk in terms of rate, because rate is very difficult for people to understand—I would put it in terms of the dosage given in time intervals.

In that connection I assume that there would be a representative value picked which I think is consistent with some of the assumptions you make in this discussion about the nature of nuclear war. I assume that the value would be roughly 2 kilotons of fission products per square mile. To be very approximate, if you took 4 megatons of fission products and distributed them over 2,000 square miles, that will give you 2 kilotons per square mile. If you do that and assume that the fallout comes down in roughly the first hour or the second hour, you will have gamma dosages which run in the following sequence: 2,500 roentgens in the first hour; half that in the second hour; between 2 and 3 hours, 800 roentgens in the 3d hour, 550 in the 4th, and then from the 5th to the 10th hours you would have a total of 1,500, and from the 10th to the 24th hour you would have 1,550 for a sum total of over 8,000 from the 1st hour. That is a maximum hazard because of the fact that much of the fallout would not come

down in the first hour because there is a transportation time for the debris.

Representative HOLIFIELD. This is using a factor of 2 as against the factor of 1 which Mr. Shafer used.

Dr. LAPP. This is using approximately a factor of 2 for various technical reasons about the fractionation of fission products, and the deviation of a plane from a billiard table. It is rather a spongy grass mat.

Then when you go over to longer times, you find that there is a real deviation from the $t^{-1.2}$ law, and it comes in the following way. If we look at the total dose which would be accumulated if you stood out in the open on this billiard table flat plain, in the second week you would get 530 roentgens which would be a lethal dose, assuming you had none before that. In the third week you would get 285 roentgens, and in the fourth week 140 roentgens. If you put it in terms of months thereafter, it drops off rather fast, because the curve then is breaking as the shorter life activities die out and the longer life activities take over.

In the second month I would anticipate 220 roentgens; in the third month, 100 roentgens; in the fourth, 60 roentgens; in the fifth, 40 roentgens, and in the sixth month, 25 roentgens. If I may just inject a word about the roentgen, you have to visualize these things and evaluate them in terms of a wartime hazard. In peacetime I am plenty concerned about a tenth of a roentgen. But in wartime I will treat 100 roentgens as acceptable. There is a difference of at least a thousandfold between war and peace. I think this has to be made quite clear.

Representative HOLIFIELD. You take that, of course, as a philosophical conclusion on your part.

Dr. LAPP. Yes; this is a personal conclusion.

Representative HOLIFIELD. Rather than a determination that a hundred roentgens is desirable.

Dr. LAPP. I do not desire 100 roentgens.

Representative PRICE. You don't desire 10, either, do you?

Dr. LAPP. That is right.

Representative HOLIFIELD. Have you fairly well stated your position on this point?

Dr. LAPP. I would like to add one additional point. A great deal of attention is focused upon the long-term activity. I believe Mr. Shafer mentioned yesterday that there would be some places that would not be inhabitable for several years.

Mr. SHAFER. No, sir. One year.

Dr. LAPP. If you look at the estimate I made here, in the second year I would project a value of approximately 20 roentgens for the total year's dose to a person standing out in the open, but assuming that some of this debris is actually weathered. I have made technical estimates which I think are fairly conservative on this. I can mention that the rate of radioactivity of decay at that time is approximately 30 times less than projected by the $t^{-1.2}$ law.

Representative HOLIFIELD. So while your intensity is greater to begin with, it dies out quicker and is much less in the later months?

Dr. LAPP. Much, much less. This is, however, the gamma ray haz-

ard, and I have not spoken of the internal strontium hazard which would be persistent.

Representative HOLIFIELD. We will get to that later.

Representative HOSMER. Before we leave that particular topic, I would like to ask Dr. Lapp this: Let us take the point under these new calculations where you get a 100-roentgen dose. These calculations of yours I think are based on the 50–50 fission-fusion ratio for this particular problem.

Dr. LAPP. Mr. Hosmer, I assume 2 kilotons of fission products per square mile. How they got there I don't care.

Representative HOLIFIELD. I was trying to relate this. If we had a difference in the fission-fusion ratio would it make a much more substantial difference than this decay rate?

Dr. LAPP. It would not change the decay rate of the fission products, but it would affect the intensity.

Representative HOLIFIELD. I mean in terms of intensity.

Dr. LAPP. Yes. The higher the fusion yield, the cleaner the bomb. The higher the fusion yield of the bomb with respect to the total yield of the bomb, the less would be the actual number of fission products per square mile, so that the intensity would be less.

Representative HOSMER. The higher the fusion.

Dr. LAPP. Yes.

Representative HOSMER. Instead of 50 percent fission, we had 60 percent fission, what would that do?

Dr. LAPP. I don't think this would make a very great difference.

Representative HOSMER. It would not?

Dr. LAPP. I don't think so.

Representative HOSMER. It would be a lesser difference than the difference in the decay rate.

Dr. LAPP. Yes.

Representative HOLIFIELD. Mr. Deal.

Mr. DEAL. I don't think I can add much to the comments that have been made by these gentlemen here on the technical point, but I think it is important to recognize the long time lag it takes from the time data are developed until they are actually used.

Representative HOLIFIELD. Three years is quite a long time. It seems that it is about time we get another nuclear weapons handbook, don't you think so?

Mr. DEAL. Yes. That is what I am coming to. It was actually longer than that, because the handbook was in preparation a year or 18 months.

Representative HOLIFIELD. Do you have another nuclear handbook in preparation now?

Mr. DEAL. I could not answer that specifically, but I am not aware of one, and I think I would know if there was a new handbook being developed.

Representative HOLIFIELD. This committee then can assume that there is not. If the chairman might be so bold as to suggest, some of these things ought to be brought up to date. Did you have any comment, Mr. Hawkins?

Mr. HAWKINS. Yes, sir. I might make one comment on the "Effects of Nuclear Weapons." There is no indication in that of the effect

of the induced radiation in uranium 238. We can refer to a British report which indicates that around 60 percent of the total activity at 4 days—activity in this case is the number of disintegrations—is due to the uranium 239 and neptunium 239 that are produced, as the British say, in either large or small weapons. I believe part of the hump on the curves in the early times, say around 4 days, is largely due to this. The neptunium does not have extremely energetic radiations so that the radiation intensity is not quite proportionate to the disintegration. But, nevertheless, it does have a significant influence at those times.

Representative HOLIFIELD. It seems to me this makes a great deal of difference in the protection of survivors in case of nuclear attack. The accumulation of roentgens being more intense at first, if shelter or shielding could be provided from those effects for the immediate intense period, then there would be lesser danger in the latter 6 months of the year or in the following year. Is this not true? I am going to get back now to Mr. Shafer because I know he has something to say.

Mr. SHAFER. Thank you, Mr. Chairman. I would like to point out actually the degree of difference with regard to what Dr. Lapp discussed and what $t^{-1.2}$ would indicate.

Dr. Lapp indicated that with his assumption the dose during the first 24 hours, with an initial dose rate of 2,500 roentgens per hour at H plus one, would be 8,150 roentgens. The $t^{-1.2}$ indicates that the dose during the first day would be 6,000 roentgens. This is 6,000 versus 8,150. That is not much of an increase, but this is not the main point I am bringing up. The point I am emphasizing is that within OCDM we are well aware of these uncertainties. This is why we have recommended a shielding factor much greater than would be required based on the $t^{-1.2}$ assumptions.

With regard to the latter part of the spectrum, the period subsequent to 2 weeks, you will recall that I stated yesterday, Mr. Chairman, we have little confidence in the dose calculations indicated on the 3-month chart. We showed an increase between 2 weeks and 3 months of about 2,000 roentgens in the most intense area. In these time periods beyond 2 weeks I stated that we had very little confidence in any dose computations and perhaps in lieu of 2,000 this dose might well be as low as 1,000 roentgens during the period from 2 weeks to 3 months. We are fully cognizant of these uncertainties, sir, and take them fully into account in our OCDM survival and recovery planning.

Representative HOLIFIELD. Did you have any comment on that, Dr. Tompkins?

Dr. TOMPKINS. I think, Mr. Holifield, the main point I wanted to bring out is that the application of this type of information since 1957 has improved to the point where one should recognize openly that the $t^{-1.2}$ law is not a basic law. It is an approximation. As long as people understand it is an approximation and use it correctly and intelligently, this will be all right.

Representative HOLIFIELD. This is why, if I had been in Mr. Shafer's position, I would have said, according to the data of 3 years ago, this is the reading we have, but according to newer data it may be twice that much. Then we would have had figures, I think, which would more approximate the new data.

Dr. TOMPKINS. I would also like to agree with Dr. Lapp's observation. I think the deviations are more significant later on than in the early time period.

Representative HOLIFIELD. Is there any further comment?

Dr. LAPP. Actually I do not think that Mr. Shafer and I are in too much disagreement on this calculation. It is very critical when you assume that the fallout came down. I didn't mention that there is an assumption here, that is, that this is straight or pure fission product activity. The question has been raised about additional activities which could be of several types. One which would be difficult to discuss, which is the activity created in the bomb itself, other than the fission products. That could be in the material of the bomb, the nonactive material, and I am sure that is a difficult problem to discuss.

The other is the fact that if the bomb goes off on the ground, as we have assumed, then there will be a very large number of different induced activities which are produced, just as material is inserted into a reactor at Oak Ridge to produce radioactive material, this material will be out in the open and the source will be a bomb, and you will have induced radioactivities in the harbor. You will have sodium 24, which will be short lived, and then you have on land many activities which would depend on the type of soil and the chemical composition. This, I believe, has not been taken into account at all.

Representative HOLIFIELD. I think this is true. While we do not want to get into the composition of bombs and the way they are built and what they contain and that sort of thing, it has been unclassified for a long time that we can make bombs cleaner and by the same factor we can make them dirtier. So the factor of any enemy who might choose to make dirtier weapons would create a different reading just as if we changed the 50–50 ratio to 75–25. Regardless of how it was changed these readings would be different. If they were changed the other way, they would be dirtier. I was getting at the comparative rate of the 50–50, and the difference in opinion on that particular reading.

Dr. LAPP. You are really discussing what is known as the filthy bomb, and we were talking about the dirty bomb. I am not so sure that the filthy bomb is really dirtier than the dirty bomb.

Representative HOLIFIELD. We won't go any further into that at this time. Dr. Shelton testified yesterday that a 10-megaton weapon with 50 percent of its yield due to fission, would produce a 600-roentgen-per-hour contour enclosing about 1,300 square miles. I believe 80 percent local fallout is assumed. This means that 4 megatons or 4,000 kilotons of fission debris is available for local fallout. If 1 kiloton spread over 1 square mile yields an H-plus-one dose rate of 2,500 roentgens an hour, then don't we have a potential for contaminating 4,000 times 2,500 over 600, or about 16,000 square miles instead of 1,300 square miles? Is there anyone who wishes to comment on that?

Dr. LAPP. I believe I could comment. If the word "potential" is used I think the answer is yes in terms of total area. It would assume that the material could be transported to this entire area quickly.

Representative HOLIFIELD. By quickly you mean?

Dr. LAPP. Within an hour.

Representative HOLIFIELD. Of course, unless you had a real gale, you probably could not cover that much from zero point.

Dr. LAPP. It would have a potential, I believe, but it would be a matter of practice of how strong the wind was as to how it was dispersed.

Representative HOLIFIELD. Let us assume the 40- to 60-knot winds which were used in the assumption. I don't want to get into a difficult computation here. What would the assumption be?

Dr. LAPP. I would like to ask Dr. Machta what he thinks of that.

Dr. MACHTA. You mean the calculations as described?

Dr. LAPP. Yes.

Dr. MACHTA. If one starts out with a certain number of megatons deposited on a certain area and converts that to roentgens per hour, the arithmetic you just described would be correct. However, in most of the calculations we do not operate in this fashion. Rather we scale from a given yield bomb from the AFSWP model. It is because of this difference of approach that we come out with different answers. What we have used in the exercise for the committee has been the scaling of the AFSWP model. It has not been based on the type of arithmetic you described.

Representative HOLIFIELD. Both you and Dr. Triffet expressed lack of confidence in the AFSWP formula. In your professional judgment, how would you change the formula in view of more recent data?

Dr. MACHTA. In two different ways. The AFSWP model, from the meteorological point of view, is based on winds, within a deep layer, up to only one altitude. It does not take into account the shear of the wind with altitude which can spread it out in the manner described by Dr. Triffet yesterday. The use of a single mean wind is an oversimplification which we should avoid.

The second change which we recommend to AFSWP about 2 years ago was a different scaling law which would not make the patterns quite as elongated for higher wind speeds. The original model is based on 15 knot mean deep layer wind. This wind speed, for the temperate latitude, is very small. The AFSWP scaling law extends the isolines to such an extent that they become almost ridiculously long and narrow. We recommended a different scaling law which we felt to be more realistic. These are the two changes I would suggest.

Representative HOLIFIELD. If the average wind speed is between 40 and 60 knots, we should not be using a 15-knot factor in the formula.

Dr. MACHTA. We do not use a wind of 15 knots. We actually scale it from 15 to say 60. It is my opinion that the scaling law is not correct, and we should be using a different one. When the "Effects of Nuclear Weapons" is changed we hope the new scaling rule will be included.

Representative HOSMER. Is it just a straight scale?

Dr. MACHTA. Yes.

Representative HOSMER. Instead of being a straight line, you feel it should be a curve?

Dr. MACHTA. Yes. Because of the fact as you spread the particles out, you also dilute, so there will be less concentrated fallout in the nearby area.

Dr. TRIFFET. Those are essentially the same comments I would make about changing the model.

Representative HOLIFIELD. Let us see if we can apply to a specific area 1 of these 10 megaton bombs. Let us assume that a 10 megaton bomb drops on a State like Missouri. The fallout from this surface burst, the same 50-50 formula of yield, falls on the St. Louis area where my friend Mr. Price lives. I am being generous with him today. I am allowing him to be the guinea pig.

Assume further that the radiation intensity at the end of 1 day is 50 roentgens an hour due to fission products. How much additional dosage would induced activities add to the radiation dose?

Dr. TRIFFET. I think I can comment on that to some extent. It has to take the form of a few qualifying comments, too, however, as you were mentioning earlier.

First of all, there have been a lot of references in our discussion to work done in NRDL to differences in the decay rate. I think it might be worth mentioning for the record the principal document is Technical Report 247 which is primarily the work of Dr. Karl Miller. I am also going to make a comment or two about the differences in the dose rate induced products make at early times.

Representative HOLIFIELD. In other words, we are thinking about a city where the induced products would be iron, steel, concrete, and asphalt and that sort of thing.

Dr. TRIFFET. Yes, sir. Part of this difference comes about because differences in energy of radiation at early times and a lot of work has been done at our laboratory by Dr. Cook.

First it is important to understand that the decay curve that I showed yesterday, the hump at early times, as Mr. Hawkins mentioned, is due primarily to the presence of induced products which I described. However, if we were to plot two curves, the t to the minus 1.2 and ours based on our data, it would still be higher at early times. This is because of the difference in the effective ionization brought about by the radiation. The difference at late times, and this might be worth mentioning—it has been mentioned frequently that the curve drops off at late times—the reason is that the total ionizing power of radiation decreases. To think of this you would have to think of the average energy that is involved in the radiation, too. This varies with time. Based on these comments to directly answer your question, the curve that I put on the board or had on a poster had a hump in it in early times. This was due primarily to the presence of induced products. That gives a reading that is about 20 percent higher at one day than if the induced products were not there. However, this is induced products in the bomb. I won't go into details what these are, but it is induced products in the bomb; products are induced in the soil or in ocean water. They would no doubt constitute a smaller percent contribution to the overall reading. So while I would not like to state a specific number for that, I think on the basis of induced products in the bomb, you might say that your roentgen figure might go to 60.

Representative HOLIFIELD. You may remember that 2 years after the Bikini burst, we had one of the ships towed back to one of the California shipyards. I believe it was still strong enough in its radioactive intensity that people were only allowed on the ship for a short

length of time. That was a case of induced radioactivity in the metal of the ship, was it not?

Dr. TRIFFET. I am not familiar with that case.

Representative HOLIFIELD. That ship was in the San Francisco area, and 2 years later it was still radioactive.

Dr. TRIFFET. I was under the impression that was from fallout deposited on the ship which would not be induced products.

Representative HOLIFIELD. They hosed those ships off. They tried to decontaminate them. I saw them working on it out there. Dr. Tompkins, you might know about that instance.

Dr. TOMPKINS. You are referring to the *Independence*, Mr. Holifield?

Representative HOLIFIELD. Yes.

Dr. TOMPKINS. I believe most of the radiation associated with that was from the fallout material.

Representative HOLIFIELD. I am sure it was. The water came down on the ship.

Dr. TOMPKINS. I want to draw a distinction that there are two classes of induced activity; one which is induced immediately around the weapon and becomes a part of the fallout material; the other, that which might or might not have been induced in the structural material of the ship itself. I thought at first you were referring to direct activation of the iron in the ship.

Representative HOLIFIELD. I don't know exactly what I was referring to. I just remember the facts of it. The reason I brought it up was to apply this, if possible, to the ironwork in skyscrapers, and other metalwork in cities. Because, if there were a residual activity in the case of the ship, it would seem reasonable to me, as a layman, that this residual activity would persist in the framework of buildings and so forth in cities.

Dr. TOMPKINS. This is true.

Representative PRICE. In that connection, since you mentioned the difference in the dose rates of weapons dropped in a salt water harbor, and also made reference that it would be different, dependent on the nature of the soil and so forth, many of our cities are on fresh waterways and rivers. Since they are going to be surface bombs, in St. Louis this could very well land in the river. What effect would that have on the dose rate?

Dr. TOMPKINS. I think for all practical purposes, Mr. Price, very little. At the yields we are talking about, I don't think the water in the river is a big enough part of the crater material that would be drawn up to dominate the character of the fallout. You would get something in between the deepwater characteristics and the land burst. The significance of that, however, is not in the dose rate associated with the induced activity. It is with the relative difficulty of getting rid of or not getting rid of the material once it is deposited. The material from dry ground cleans up very easily if you get at it before rain. The material from deepwater shots does not clear up very easily. The case that you mentioned here would have a greater significance on the fact that it would be more difficult to clean up than some other types of debris and might even in fact be like the material Mr. Holifield was talking about which came from a sea-water shot.

As water ran down the cracks, quite obviously the only way you are going to decontaminate that is to take all the cracks out.

Representative HOLIFIELD. When I brought up the subject of a sea-water burst, I was really thinking of the map and the fact that the winds are from west to east. An enemy could design a salt-water burst in the Los Angeles Harbor or San Francisco or Seattle Harbor. The resultant contamination of the city might be lethal in its nature and yet not destroy the structures of the city as it would if the bomb were burst in the city itself.

Dr. TOMPKINS. I see your point. May I start off my making a comment on this particular point.

This is one of the subjects I did want to get into but it is not what I would call new information. It is a point of clarification. I think it is quite true that the radiation levels, particularly close in, tend to be quite lethal. However, I would like to make the following comment and get some of the other panel members to take a poke at it.

Around a city you have all kinds of structures. Some of these are knocked over at 10 pounds per square inch, some at 3, 4, and 5, and some at lower levels. I just call attention to the fact that somewhere around one or less pounds per square inch, windows disappear and one of the greater hazards in metropolitan areas as far as the people are concerned is the great amount of flying glass that would be going around even though the structures themselves are not particularly damaged as such. On the other hand, from the fallout material, we are talking at this point about information that would have been developed by Dr. Eisenhaur had he given his testimony.

Representative HOLIFIELD. I want to make it clear that this is Dr. Charles Eisenhaur we are talking about, who is well informed on this particular subject.

Dr. TOMPKINS. Yes. He works for Dr. Taylor of the National Bureau of Standards.

Representative HOLIFIELD. And he spells his name "haur" rather than "hower."

Dr. TOMPKINS. I think the clarification is well made. The point I wanted to make is that the one story buildings about 20 feet high, can give protection from the fallout radiation. As a matter of fact, you will find within any metropolitan complex some types of buildings where radiation protection comparable to take that which Mr. Shafer talked about, but not quite that good, already exists. Therefore, one of the points on relative vulnerability that I would like to leave with you is the fact that in a city the relative vulnerability is high with respect to blast and consequently the thermal effects. But because of the very nature of the buildings, it is far less vulnerable to the effects of fallout than are the smaller communities with their small buildings, the agricultural and the rural areas. Consequently, I would answer first of all that whatever gross predictions one would make on so-called free-field data which are applicable primarily to agricultural communities, when applied to a city would tend to overestimate the probable threat to Los Angeles from that source just a little bit. I don't want anyone to imply from this that I don't think Los Angeles would not be in serious trouble. I think it would be.

Representative HOLIFIELD. In our Thursday program we expect to bring out the damage that will be done to the different cities. I hope that the men in your organization, Mr. Shafer, who are working on this will give us both their computations on the old data and the new data. Perhaps I should reverse it, on the new data as well as the old data, if they can, by extrapolation.

Mr. SHAFER. At this late date I am not certain that we can do it on the basis of the new data. This is a machine print out and the t to the minus 1.2 data are stored in the memory drums of that machine.

Representative HOLIFIELD. Will it be possible to make an approximate extrapolation?

Mr. SHAFER. With regard to blast, they will not be affected anyway. This will only be from fallout.

Representative HOLIFIELD. You could give an extrapolation at that time of what you might call a good calculated estimate, could you not?

Mr. SHAFER. We shall certainly attempt to do this, sir. I would like to comment on another subject if I may.

Representative HOLIFIELD. Let us have Dr. Triffet comment on this subject first.

Dr. TRIFFET. I agree with the remarks that were made relative to the hard targets in the cities. The comment I was going to make was on your question of induced activities. I think there might be a mild point of confusion there that should be clarified.

If you take a given amount of iron, it is capable of producing a certain amount of induced activity if it is irradiated with neutrons. If this ends up in the fireball, then it probably will end up in the fallout. On the other hand, if it doesn't get in the fireball and still may be irradiated, it can still be activated and become radioactive.

It turns out that any point outside the fireball that is close enough for appreciable amounts of induced activity to be created by the neutrons, there are probably other hazards that would override, in terms of casualties.

Representative HOLIFIELD. Immediate casualties?

Dr. TRIFFET. Immediate casualties. This has to be qualified in terms of hard and soft targets.

Repreesntative HOLIFIELD. Yes.

Dr. TRIFFET. However, there are cases where these induced activities might be important. For example, a building that was not destroyed by blast, that was irradiated with enough neutrons to activate the managanese 56 in the iron such that people who were there originally would have been killed from prompt neutrons and gamma rays. But people who came in later to use the building might receive an appreciable radiation dose from the induced activity.

I wanted to draw that distinction.

Representative HOLIFIELD. This is one of the reasons I brought it up. I remembered the long-term radioactivity of the ship that was towed back to the California coast. In such a case as we have now discussed, if you apply the old data, the $t^{-1.2}$ data to the old building, it would remain for a much longer period of time than the new data which assumes a more rapid decay.

Dr. TRIFFET. This we have to be very careful with. Ordinarily in the case of induced activity it is a single radioactive product that

decays. The $t^{-1.2}$ is the decay rate. These figures that we have represent the combined decay rate of many products and you cannot make this crossover. You have to make it in terms of the material.

Representative HOLIFIELD. Mr. Hawkins.

Mr. HAWKINS. Mr. Chairman, may I perhaps clarify a point that may be misconstrued relative to the ship, *Independence*. I was working at the Naval Radiological Defense Laboratory at the time the ship was disposed of, which was probably about the time you visited the ship. I can't recall the radiation intensity but it should be kept in mind that the precautions taken relative to persons being on the ship at that time were related to peacetime standards. In other words, a maximum of 50 milliroentgens per day and probably controlled at a level of a fourth of that. In other words, even when there is possibility of getting less than 50 milliroentgens per day, precautions are taken.

Representative HOLIFIELD. I recognize that fact. This same thing would obtain after a nuclear war. There would be a peacetime period and there would be exposure to residual radioactivity.

Do you happen to remember how long that ship was radioactive?

Mr. HAWKINS. She is radioactive yet in the broader sense, even though she is at the bottom of the Pacific.

Representative HOLIFIELD. You finally took that ship out, after how many years, and sunk it?

Mr. HAWKINS. It was about 1952 or 1953.

Representative HOLIFIELD. And the exposure was July 25, 1946. In 1952 you took the ship out and sunk it in the deep part of the ocean because it was still radioactive?

Mr. HAWKINS. The reason for sinking it was more related to the fact that it was more economical to sink her than to try to recover her.

Representative HOLIFIELD. You did testify that it was still radioactive?

Mr. HAWKINS. Yes.

Mr. DEAL. I would like to make one comment to reinforce what Dr. Tompkins was saying about the shielding of buildings. We did a study of the shielding of the Atomic Energy Commission headquarters building. Our basement area, which is completely underground, gave us a shielding factor of something over 10,000. The first floor was something around a hundred. The second and third floors ran somewhere around 200 to 600. And the top floor was back around 100. We have a report on this coming out. It is not completed yet. These are kind of preliminary numbers but they do represent an order of magnitude.

Representative HOLIFIELD. Would this be to a certain extent, in the case of the upper levels, due to the fact that it was further away from the ground.

Mr. DEAL. Yes. The building has something like 25 percent glass, which is about normal for that type of construction.

Mr. HAWKINS. I would like to ask Mr. Deal a question. Was the fallout on the roof simulated?

Mr. DEAL. Yes.

Representative HOLIFIELD. I want to get back to this glass factor in a moment but Dr. Triffet has a comment.

Dr. TRIFFET. Yes. I thought this might be an appropriate place to comment on the variation of the average energy. It is clear when you think of shielding, because the effectiveness of shielding depends directly on the average energy radiation from the deposited material. As I mentioned, Dr. Cook at our laboratory has done quite a bit of work on this. What it amounts to is that at one hour the average energy is about one Mev. This appears, by the way, in the tables that are in my written statement but that I did not present orally.

Representative HOLIFIELD. Mev. means?

Dr. TRIFFET. Million electron volts. At 2 hours it drops to 0.95. At a half day, to 0.6. At 1 week it drops to 0.35. Then it begins to go up again. At 1 month, it is 0.65, 2 months 0.65. The meaning of this is simply that there is a period around 1 week when if induced products are important in the bomb, there are a lot of radiations emanating from these, but the energy is low so it operates to reduce the average energy in this period and shielding is immensely more effective.

Representative HOLIFIELD. Did you have an additional comment on that, Dr. Lapp?

Dr. LAPP. I think you would not include sodium in that category.

Dr. TRIFFET. No. This is an environmental effect. The activity I was referring to is an induced activity in the weapon.

Representative HOLIFIELD. I believe it was testified yesterday that the buildings 25 miles away would suffer a great deal of glass damage from a 10-megaton weapon. In view of the fact that we have several million schoolchildren in schools throughout the Nation and most of these schools have a very high percentage of exterior walls and glass, will not this constitute, within itself, one of the great hazards in this type of war? I am thinking of the areas that are far removed, as far as 15 or 25 miles, from the immediate blast damage in the central area.

Would this not constitute a tremendous damaging factor?

Mr. DEAL. Mr. Chairman, I might be stealing some of Dr. White's thunder, who is testifying on the blast problem this afternoon——

Representative HOLIFIELD. We will withhold that because we don't want to steal anybody's thunder. It is bad enough to steal their radioactivity. There is one factor we considered on all these different bombs. They have been surface bursts. The factor of extension of the heat of the fireball has been predicated upon the surface atmosphere, the close-to-ground atmosphere, the thickness or humidity or other qualities in the earth's atmosphere. Would there be a difference in a bomb exploded, let us say, 25 miles in the air. I am thinking of heat transference, or 40 miles in the air, as against the transference of heat along the ground level. If so, what would that factor of five be? We recognize that the air gets thinner as it goes up and there would be less resistance to heat transference. I think Dr. Shelton testified to that. He is not here today.

Is there anybody who would like to pick that up?

Dr. TOMPKINS. I will start in qualitatively, Mr. Holifield. I think what would happen is that as the altitude went up the increased fraction of the total energy going out in the thermal would increase the amount of heat generated.

If it got high enough so that much of the path was not through the dense part of the atmosphere but was perhaps through more rarified parts, it would tend to expand potentially the cone of damage. This would vary quite a bit because the total energy would depend on the slant range. I would expect, therefore, that a maneuver of that kind would increase the thermal damage radius. It would decrease the blast and eliminate the fallout. That would be just about it.

Representative HOLIFIELD. Would it be possible for you to pin the 10 megatons down in terms of the fission, that we were given yesterday, of the ground burst and transfer that to an air burst and give us any figures on that?

Dr. TOMPKINS. I will certainly make a guess at this time. I tried to find a combination of distances of this type that would extend the thermal damage radius out to 40 miles.

Representative HOLIFIELD. From 25 to 40 miles.

Dr. TOMPKINS. Would you question that, Dr. Lapp?

Representative HOLIFIELD. What would you think of that, Dr. Lapp?

Dr. LAPP. Could I use the blackboard?

Dr. TRIFFET. There is one comment I might make on this, that in the written statement I submitted I did indicate that certain combinations of theoretical and experimental results that we have now indicate that if such a hit comes these proportions almost reverse themselves.

In other words, we are talking about 85 percent of the total energy of the bomb. On the surface the division is usually 50 percent blast and 35 percent to heat light. We can reach a state of affairs where these two proportions can just reverse themselves.

Representative HOLIFIELD. I see.

Are you ready, Dr. Lapp?

Dr. LAPP. Yes. If this blackboard were black I could get some contrast to show what I mean.

Down by the earth's surface you would have one-third of the earth's atmosphere at about 3 miles you have an atmospheric pressure of one-third. So one-third is above and two-thirds below.

If you consider how the earth's atmosphere varies, if you detonate the bomb at 40 miles, there is practically no atmosphere. You have just eliminated the earth's atmosphere. A bomb which is detonated at the earth's surface, according to Dr. Shelton's testimony yesterday, would produce blistering on the person's skin if he were exposed without protection at a distance out to as much as 25 miles. I assume that the assumption was that it was fairly clear air. The rays in going from the point of detonation out to 25 miles are traveling through the heaviest part of the atmosphere that is at the surface. This is not drawn to scale. I will draw it to scale.

If this is a 40-mile burst then the rays go through the heavy absorbing part of the atmosphere to a very slight degree. One might define this in terms of standard atmosphere miles. This would be 25 atmosphere miles and this would be going through perhaps three atmosphere miles, or something like that. This would then be essentially an inverse square calculation.

In this case if there were a blistering on the person's skin, then if you detonated here so you do not look through the atmosphere,

I would expect that there would be a greater area over which the bomb could produce its radiation effect. I would say in this case I would like to see some experimental data.

Representative HOLIFIELD. Of course, we cannot do that. We are in a bomb test cessation. Maybe there will be some time in the future.

Dr. LAPP. I think there have been two bursts at high altitude.

Representative HOLIFIELD. That is right. Maybe the Johnston Island burst. Maybe we have some information. There was some land but a great deal of ocean there. I don't know whether the readings on that are available or not. Is there any wonder that nobody knows what the readings were?

Dr. TOMPKINS. I think that will be discussed by Dr. Ham. I don't know if he will talk about particular numbers, but he would cover the subject.

Representative HOLIFIELD. Is there any comment from the panel on the formula that has been placed on the board which would seem to indicate your heat damage could be extended in a radius of approximately 40 or 50 miles rather than by just exploding the bomb in the air? If that is true, would the degree of heat that would reach the earth out that far be enough to burn corn crops and wheat crops, or anything like that? I recognize most of the wheat would be harvested in October, but the corn would still be in a pretty dry condition in many instances.

Dr. LAPP. The answer to that depends upon the condition of the crop and the earth's atmosphere at the time. But if it were perfectly clear then I would think the area over which a single bomb could produce these effects on human skin which would run about seven calories per square centimeter for second-degree burns would at least go out to 40 miles for a multimegaton bomb detonated at 40 miles up.

Representative HOLIFIELD. That is a 40-mile radius. Give me a quick computation on the square miles that would cover.

Dr. LAPP. That would be about 5,000 square miles, would it not?

Representative HOLIFIELD. 5,000 square miles.

Dr. LAPP. Yes. I think that everything depends here upon what you would call optimizing the effect. The bomb detonated at Hiroshima was detonated at the optimum altitude to produce maximum blast effect. You could calculate what would be the maximum altitude to maximize the thermal effect to produce a scorched earth policy. Burning of crops would be more difficult than burning people.

Representative HOLIFIELD. But there would be damage to people in that area?

Dr. LAPP. I would think so; yes.

Representative HOLIFIELD. Would you agree with that, Dr. Tompkins?

Dr. TOMPKINS. Yes, sir. That is essentially the comment I wanted to make. If I may comment on our own attack pattern, the particular attack pattern we have set up for the study does not maximize all effects. We want to be sure that everybody is aware of that. The one we have does maximize the blast effect on what might be called hard targets. A high altitude detonation will not destroy a railroad yard or something of that type. The attack pattern we have can

because we can put a hole in it. The second thing that it does is that it gives maximum blast pressures. By being close to the ground it also maximizes the fallout radiation problems.

The attack pattern we have more or less evens out all of the effects and gives a good coverage of each.

Representative HOLIFIELD. From the standpoint of striking a balance, then, you would say that this attack pattern the committee has presented is a balanced attack pattern and takes into consideration most of these factors?

Dr. TOMPKINS. From the standpoint of the relative weapons effects it is a good balance. This is quite apart from any military characteristics.

Representative HOLIFIELD. Mr. Shafer, you had your hand up a moment ago.

Mr. SHAFER. With regard to irregularities of fallout deposition, Dr. Triffet showed yesterday an analysis of a multimegaton detonation in the Pacific in which there was a tremendous fanning out of the fallout with several hot spots.

I would like to make it clear to the committee that this particular type of wind behavior, such as exists in the South Pacific, is very typical as far as the United States is concerned. We do not have that type of wind behavior in the United States except possibly in the Gulf States in the summertime, only one season out of four. In the particular season we had under study, the fall season, October 17, 1958, the tropical easterlies did not exist anywhere in the United States and up to 60,000 feet altitude there were no easterlies even in the high stratospheric regions. So that the pattern which Dr. Machta showed would be more typical of what we could expect. But the primary thing that I want to point out is that in the event of an actual emergency we would not go through this theoretical approach to determine the location of fallout. We would do this by monitoring. To this effect we have distributed some 90,000 survey meters to the States and the local governments, some 60,000 to the Federal Government, and an additional 60,000 to the high schools. In the event of an emergency all of these 200,000 plus instruments would be used to rapidly monitor the fallout.

Representative HOLIFIELD. Are these mostly instruments that show radioactivity but do not quantitatively measure it?

Mr. SHAFER. They do both, sir. They detect it and indicate the dose rate in roentgens per hour, both gamma and beta discrimination and they indicate the accumulated dose.

Representative HOLIFIELD. How often are they calibrated, and are they dependable?

Mr. SHAFER. At the present time we are developing a calibration program. Some of the States, California, New York, and others are doing very well in calibrating their instruments. We are developing a calibration instrument using 20 curies of cesium 137 which will allow all of the States to calibrate their instruments. Further, our monitoring instruments are very dependable.

As you know, we do have before the Congress at the present time legislation to get sufficient funds to procure monitoring instruments. Additional instruments will be needed this year to set up some 37,000 monitoring points across the United States. We have asked for $8.5

million, as you are well aware, and approval has been granted for only $1.5 million so far.

Representative HOLIFIELD. This is one of the reasons this hearing is being held, to bring to the attention of Congress, as well as the people, the type of hazard which we face.

Mr. SHAFER. And the necessity for obtaining sufficient instrumentation to rapidly determine the location and intensity of the fallout situation.

Representative HOLIFIELD. That is certainly one of the points that are important, but there are a great many more, as you know, that are equally important. Are there any comments on any subjects which we have discussed here this morning or questions which need clarification in the mind of any person present. Dr. Triffet.

Dr. TRIFFET. This is a comment on something that was discussed yesterday and that I have been surprised was not brought up today. We have emphasized today in our discussion two of the deviations from theory which I emphasized yesterday, namely, deviation from $t^{-1.2}$ and the irregularity of contours. The third deviation from theory that I stressed was fractionation. It may be that I didn't get this concept across clearly enough. I would like to emphasize for the record that in our minds at least this is one of the most important subjects that needs more exploration for the future. This bears both on the local hazard and the worldwide, but it is perhaps more important in terms of the worldwide hazard in fallout since it appears that strontium 90 cesium 137 may be enriched in worldwide fallout as a result of fractionation.

Dr. LAPP. May I make one final general comment?

Representative HOLIFIELD. Yes.

Dr. LAPP. I believe with regard to any analyses made of the civil defense problem it is extremely critical what megaton assumptions you make. This means that as you advance into the 1965 and 1970 periods that the megaton assumptions inevitably go up. Not that you will pattern the megatons to the target but that the weapons will speak for themselves. The weapons with continued testing will get bigger. I believe, for example, on that diagram on the blackboard that it would make the calculation on a 10-megaton bomb one thing. But if we make the calculation for 40 megatons, it is another thing. Then the areas go up from 5,000 square miles to areas which are actually larger than the fallout area. So I think this bears out what Dr. Frank Shelton, the technical director of the Armed Forces Special Weapons Project, said yesterday, calling attention to the fact that other effects of the bomb may outrank things which have received greater publicity in the past.

Mr. SHAFER. At the same time you would not advocate discouraging the American public from building fallout shelters in their homes?

Dr. LAPP. I had not made any statement with respect to that. I was merely stating that the megaton assumptions may get very critical as to the feasibility of the entire defense effort.

Representative HOLIFIELD. Isn't it true, also, that when we harden our bases, by placing missiles in concrete silos and underground concrete structures, if an enemy is to attack those successfully, the 1,500 megatons we have talked about here would be completely ineffective? You would have to move into the field of 10,000 or 20,000 megatons

in order to have any effect at all on hardened missile bases. Isn't that true?

Dr. LAPP. I think this depends where your bases are and how hard they are. I think that your levels of attack of 10,000 or 20,000 megatons would be in my opinion a reasonable level for the 1965 and later period.

Representative HOLIFIELD. Is there any comment on that?

(Supplementary material furnished by Dr. Lapp follows:)

ARLINGTON, VA., *July 8, 1959.*

HON. CHET HOLIFIELD,
Chairman, Special Subcommittee on Radiation, Joint Committee on Atomic Energy, U.S. Congress, Washington, D.C.

DEAR MR. HOLIFIELD: It was a pleasure to be asked on June 23 to be a witness before your subcommittee investigation on "The Biological and Environmental Effects of Nuclear War."

My testimony that day concentrated upon certain aspects of weapon radiation that have concerned me in the past year. I am taking this opportunity to submit a supplemental statement amplifying my comments on June 23. I am also attaching two articles from the May issue of the Bulletin of the Atomic Scientists; you may wish to include these in the committee record.

I believe that your hearings will be of the greatest value not only to the nonmilitary defense of our Nation but also to our overall security.

Sincerely yours,

RALPH E. LAPP.

SUPPLEMENTAL MATERIAL ON RADIOACTIVE FALLOUT SUBMITTED TO THE SPECIAL SUBCOMMITTEE ON RADIATION. INVESTIGATION OF THE BIOLOGICAL AND ENVIRONMENT EFFECTS OF NUCLEAR WAR

During the course of the panel discussion on June 23, 1959, I introduced some recent data on local radioactive fallout; the new data have two significant effects:

(*a*) The data on the radioactivity of the gross fission products of uranium have been analyzed and show that the initial intensity is considerably greater than that specified in the 1955 "Effects of Nuclear Weapons." According to the latter reference, the activity of fission products 1 hour old deposited uniformly over 1 square mile should correspond to an intensity of radiation producing a dose of 1,250 roentgens/hour at a point 3 feet above an infinite flat plane. It is assumed that the level of contamination corresponds to 1 kiloton of fission product equivalent per square mile. The new data described in the attachment ("Local Fallout Radioactivity" published in the May issue of the Bulletin of the Atomic Scientists) lead to a 1-hour reference dose rate of 3,500 roentgens per hour. This is approximately three times the value given in "The Effects of Nuclear Weapons." In practice, it would appear that a realistic estimate would correspond to about twice the old value of 1,250 roentgens/hour. The effect of this development is to significantly increase the initial gamma ray hazard in the local fallout field.

(*b*) The official publication, "The Effects of Nuclear Weapons," as well as many statements issued by the Atomic Energy Commission point to a rate of decay of fission product activity as following a $t^{-1.2}$ rule. This approximation was never really intended to apply rigorously to the fallout dosage problem and certainly not for long period of time after weapon detonation. The work of the U.S. Naval Radiological Defense Laboratory, of the National Bureau of Standards, and of independent scientists permits a more realistic evaluation of the rate of decay of fallout activity. From a civil defense viewpoint, one must take into consideration the fact that the earth is not a hard, smooth infinite plane; the fission products will tend to sink into the earth's soil surface and the surface dosage will be reduced accordingly. I have proposed that instead of a $t^{-1.2}$ rule that the following approximation be substituted: $t^{-1.3}$ up to 3 weeks after H-hour, $t^{-1.5}$ from 3 weeks to 6 months. Beyond 6 months, the rule will approximate a t^{-2} relation but this will be dependent upon the nature of the soil surface, induced activities present in fallout and the physical-chemical properties of the fallout particles. Over long periods of time when cesium 137 predominates the fallout hazard will depend as well upon the degree of fractionation of this fission product.

DEFICIENCIES IN KNOWLEDGE ABOUT FALLOUT [1]

1. Nuclear tests have been designated to minimize local fallout and only fragmentary data are available on heavy fallout associated with megaton bursts. This is illustrated by inadequate knowledge of such a fundamental feature of fallout as the fraction of nuclear debris depositing in the local fallout. Defense Department officials cite a value of 80 percent local deposition. AEC officials have cited much lower percentages for the local fallout.

2. Another area of ignorance is the estimation of the fractionation of the fission products. This influences the dosage estimates in the local fallout field especially in terms of such important emitters as cesium 137 and strontium 90 both of which have gaseous precursors in the fireball. Strontium 90 is, of course, a beta emitter and does not affect the gamma dose rate but cesium 137 is the dominant gamma emitter for long term activity. It is important to know how the local fallout is depleted in this radioisotope.

3. The data available on fission product activity apply to slow fission in uranium 235. There are no publicly available reports on the dose rate associated with fission products produced by fast fission in uranium 238. The shape of the fission yield curves in U^{235} and U^{238} is different and the shape of the fast fission curve differs markedly from that for slow fission. Radioisotopes such as ruthenium 106 and antimony 125 are unimportant for U^{235} but become significant for fast U^{238} fission.

4. Quantitative data on the contribution of neutron-induced activities to the local fallout radioactivity are lacking. So far the problem has been treated qualitatively and it is apparent that classification of certain data inhibit public discussion of the hazard.

5. Very little is known about the local fallout patterns, especially in terms of the "fine structure" of fallout over an inhabited area. One needs to know how the dose rate varies for builtup communities where micrometeorology, hard macadam or concrete surfaces, and the irregular profile of buildings causes uneven distribution of the fallout debris.

6. There is an urgent need for reliable data on the physical and chemical behavior of fallout particles on soil surfaces, on building materials and on surfaced roads. One needs to know the degree to which such surfaces are naturally decontaminated by weather and in addition one needs to know how they may be cleaned up artificially. These data must be declassified and available in understandable form.

7. It is important to know how much fallout debris may seep into or otherwise enter typical buildings. Witnesses presented some data on the contribution of roof versus ground contamination to the dose at various places inside a house. I do not recall any discussion of the radiation dose that might be expected from "inshelter" contamination.

ESTIMATING THE DEGREE OF INTERCONTINENTAL FALLOUT

One consequence of the new decay data on radioactive fallout is that the total dose integrated from time of deposition to X years is considerably smaller than previously calculated on the basis of the $t^{-1.2}$ law. This not only has a critical bearing on the civil defense issue in that it reduces the inshelter residence time and permits rehabitation of heavily contaminated areas more quickly than previously estimated, it also means that the radiation dose at places remote from the local fallout is also greatly reduced.

To illustrate the problem, we may consider the intercontinental fallout resulting from a high level attack of 10,000 megatons upon the United States. Let us now estimate the first year radiation dose that might be expected in the U.S.S.R. as a result of its own weapons. Let us further assume that the weapons detonated are of high fission yield, i.e., two-thirds fission, one-third fusion so as to produce maximum contamination and thus "optimize" the casualties due to fallout. Assume that the bombs are deliberately contact-fused or surface burst and that two-thirds of the fall out occurs locally, the remaining third being committed to the atmosphere. This amounts to a commitment of 2,200 megatons of fission products to the atmosphere. The majority of this debris is assumed to enter the stratosphere.

[1] Discussion is limited to physical aspects of fallout.

We now apply to different methods to estimate the radiation dose in Russia. Method A is empirical and is based on scaling up data on test fallout; it probably underestimates the dose. Model B is a theoretical approach that probably overestimates the dose.

Method A.—Of the 92 megatons of fission products released to the atmosphere in tests by three nations, one-third of this yield is assumed to be locally deposited, and one-third is still circulating in the atmosphere. The rate of fallout from the debris are known to depend upon a number of factors, the latitude of injection being most critical. We may assume that a commitment of 60 megatons to the atmosphere produces a 1-year total dose of 0.01 rad. If we apply a linear scaleup factor of 2,200/60=36+ we may estimate a total dose of 0.36 rads to a person fully exposed on Soviet soil.

Method B.—In order to make an estimate closer to an upper limit, assume that the bomb cloud moves from the United States to the U.S.S.R. and remains confined to a 30° latitudinal zone. Assume that an average deposition time of 2 weeks is valid and that about 10 percent of the atmospheric burden or roughly 200 megatons falls out over an area of 2 million square miles (one-fourth the land area of the U.S.S.R.). This amounts to a level of 0.1 kiloton per square mile and is certainly more a "dumpdown" than a "fallout." Using the new data on fallout dosage, I estimate that the first year radiation dose would be 47 rads.

It would seem that some value in between these upper and lower limits would be a reasonable estimate, perhaps, of the order of 3 r. I do not think that such a backlash radiation dose would be a militarily significant factor in Soviet planning.

Naturally, the radiation dose to lands below the Equator would be considerably less than that calculated above and as a rough approximation could be taken as 1 rad for the first year. The 2,200 megatons of fission products would involve the release of approximately 1 billion curies of cesium 137 to the atmosphere. If one-tenth of this fell out in the Southern Hemisphere, corresponding to 1 curie cesium 137 per square mile, the 50-year radiation dose would amount to 1 rad if no allowance is made for surface roughness or weathering. I would guess that the actual 50-year dose in populated areas would be in the vicinity of 0.1 to 0.2 rad.

The global radiation dose could be increased by the deliberate use of neutron-induced activities in the bomb environment. By selecting an appropriate radioisotope of half life shorter than 27-year cesium 137 the radiation dose could be increased. Cobalt 60 with a half life of 5.3 years has been mentioned frequently in the press. This half life is still long compared with times considered to be militarily decisive. The substitution of a "deadweight" material in the bomb in place of uranium which produces high explosive and radioactive yield does not appear of military value, especially since it automatically increases the "lashback" dose which would fall upon the aggressor's soil. In terms of global distribution, the observed fallout from high-yield nuclear weapons detonated in the middle-to-high latitudes shows a strong preferentiation in the same hemisphere with reduced leakage to the opposite hemisphere. This feature alone argues against the concept of global annihilation due to direct radiation effects.

While physicists may define the extent of the radiation hazard from nuclear detonations, they should qualify their conclusions about the probable biological effect of a nuclear war. Intercontinental and interhemispheric fallout may not be of military significance and not of acute biological effect; this does not mean that the ultimate consequences of fallout are limited to the country under attack. Huge populations which survive fallout but undergo severe irradiation may represent a breeding ground for untyped viruses that multiply quickly in a weakened population and go on to spread pestilence to other nations. Moreover, there is little actual experience with radiation ecology and one should be cautious in making sweeping statements and generalizations about the biological consequences of nuclear war.

PLANNING ASSUMPTIONS ON CONTAMINATION LEVELS

A level of contamination corresponding to an average of 2 kilotons of fission products per square was assumed in the analysis made in the attachment. This means a level in which the fission products associated with a nuclear explosion with a fission yield of 2 kilotons are distributed uniformly over an area of 1 square mile. Or, to be specified to megaton-range weapons, it means

a level in which 1 megaton of fission product equivalent is spread uniformly over 1,000 square miles. Such a uniformity is, of course, a purely hypothetical distribution and in practice one would expect tenfold variations in the fallout activity over such an area. Nonetheless it is a useful planning assumption. Furthermore, it is consistent with contamination levels to be expected for attacks involving on the order of 10,000 megatons. Assuming a two-thirds fission yield and two-thirds local fallout the deposited debris would amount to 4,400 megatons of fission products. This fallout would be expected to concentrate on less than two-thirds of the U.S. continental land area so that the average level of 2 kilotons per square mile is a reasonable estimate.

The 1-hour reference intensity associated with a 2 kt per square mile contamination could in theory be as high as 7,000 r per hour; this assumes that all the fission products are deposited with zero fractionation and that the surface on which deposition takes place is an impermeable, smooth infinite plane. I have assumed a value of 4,000 r per hour in order to be conservative but I would estimate that 5,000 r per hour might be closer to the mark.

However, if we assume a radiation field with a 1-hour reference rate of 4,000 r per hour we can follow the decay of the activity and compare the variation with time. The following schedule of radiation doses for various time periods applies:

Time interval	Radiation dose in rads		Factor [3]
	$t^{-1.2}$ rule [1]	New estimate [2]	
1st day	[4] 4,000 r	[5] 4,000 r	
2d day	1,400 r	950 r	1.5
3d–7th day	2,080 r	1,320 r	1.5
2d week	920 r	535 r	1.7
3d week	480 r	285 r	1.7
4th week	320 r	140 r	2.3
2d month	700 r	220 r	3.2
3d month	360 r	100 r	3.6
4th month	240 r	60 r	4.0
5th month	180 r	40 r	4.5
6th month	130 r	25 r	5.2
6th–12th month	500 r	60 r	8.3
2d year	430 r	20 r	21.0
3d year	220 r	6 r	36.0
4th year	140 r	3 r	46.0

[1] Assumes a smooth plane (billard table) and no weathering. Data are taken from U.S. Naval Radiological Defense Laboratory report, "Radiological Recovery of Fixed Military Installations" August 1953.
[2] Assumes a rough, weathered surface and deviations from the $t^{-1.2}$ law according to USNRDL Report TR-247 (August 1958) but with no allowance for uranium 238 fission products differing from uranium 235 fission products in their radioactivity.
[3] If one compares the values given in the 2 columns, the reduction factor listed in the last column results. Note that if the factor of 2 is assumed in comparing fallout fields with the same level of contamination (defined in kilotons per square mile rather than in r per hour) then the last column must be multiplied by a factor of 0.5.
[4] Approximate estimate. 1st day dose is very sensitive to assumed effective time of fallout.
[5] Assumed to be the same as 1st column value since uncertainties in time of fallout are greater than other variations.

SHELTER CONSIDERATIONS

Inspection of the schedule of radiation doses (col. 3) shows that a person exposed in an open field would receive a total of about 7,000 r in the first week. In the basement of a two-story frame house he might have a protection factor (PF) of 20 providing that no great amount of the fallout penetrated and lodged inside the house. This would still yield a first-week dose of 350 r and would be near lethal. From a standpoint of sheer survival (and not minimizing aftereffects of radiation) a PF-100 would be desirable. This would allow for the accumulation of additional dosage during the succeeding weeks in the postattack period.

If a person has access to a good basement, there are a number of last-minute measures that can be taken to boost the existing protection factor of 20 to a higher value. For example, in many areas a determined and motivated individual could dig small tunnels into the basement wall (this would be less feasible where the earth surface is rocky). Or he might improvise a "radiation igloo" in a corner of the basement by stacking up all available objects or by filling pillow cases with dirt. In view of the fact that almost no shelters have been built in the United

States it would be very useful for the Government to provide the citizen with information about the practical value of such last-minute emergency shelter measures.

There are many areas where houses are not provided with basements. It would appear that the best protection available to people in such areas would be found in hastily dug foxholes or slit trenches. In view of a similar problem existing in the tactical employment of nuclear weapons, it is reasonable to suppose that field data are available on the performance of such shelters. These data ought to be made available to the public.

Considerations on the time occupancy of subsurface shelters appear in the attachment.

The National Academy of Sciences has accumulated a mass of data on the survival of Japanese exposed to the A-bomb detonations at Hiroshima and Nagasaki. While both bombs were in the "nominal range" and approximately 500-fold smaller than the multimegaton strategic weapons of today, nonetheless the two bombings in Japan represent our only experience with human casualties within range of the primary effects of nuclear weapons. Even though there was no casualty-producing fallout in either bombing, the data are still of value today. It would be useful to have the National Academy of Sciences prepare a summary report on their findings and relate these to the strategic weapons of today.

I was very much impressed when I analyzed data on Japanese survival that many modern structures withstood the primary effects quite close in and provided very good shelter. This impression was enhanced when I visited Hiroshima and inspected the buildings in which survival rates are high.

CASUALTY ESTIMATES

There are so many assumptions involved in estimating the casualties to be expected for any specific level of attack that I cannot comment intelligently upon the values arrived at by the OCDM in its analysis prepared for the subcommittee. For example, I do not know how many, if any, fire-storms were assumed to take place following the assumed attack. Nor do I know what shelter assumptions were made by the OCDM analysts. Still more uncertain is the degree to which the analysts considered deaths produced as a result of improper sanitation, unavailability of food and the prevalence of war-spawned virulent diseases.

If one assumes an unprepared population against which an enemy directs an attack with high-yield contaminating weapons, it is possible to make quantitative estimates of radiation deaths resulting from the fallout effects. Naturally, the estimates depend upon the level of attack, the nature of the weapons and the targeting assumptions. With respect to the latter one may define three possibilities:

(*a*) An attack aimed at maximizing deaths in the civilian population;

(*b*) An attack directed primarily against strategic military bases such as air and missile sites.

Drs. Hugh Everett II, and George E. Pugh of the Weapon Systems Evaluation Division in the Institute for Defense Analyses have carried out such analysis[a] in which they assume an enemy nation carries out its attack with weapons having a two-thirds fission yield. They calculate the percentage of deaths occurring within 60 days after an attack upon an unprepared U.S. population. Their analysis cover a range of 100 to 50,000 megatons of total yield in the nuclear weapons. The attached (p. 9) illustration is derived from figure 12 in their published analysis. All weapons are assumed to be surface burst and fallout is assumed to reach the ground at 6 hours after the bursts. The attack is assumed complete within a matter of 2 or 3 days.

I believe that this estimate made by the Institute of Defense Analysis should be given the most careful consideration especially in terms of the assumed megatonnage in the level of attack. Note that for levels of attack of about 2,000 megatons produces 20 percent mortality (attack on strategic bases) and 55 percent (attack on population). For a 5,000 megaton attack the two figures rise to 47 to 80 percent, respectively. A 10,000-megaton attack produces

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[a] Published under the title "The Distribution and Effect of Fallout in Large Nuclear-Weapon Campaigns" in Operations Research, vol. 7, pp. 226–248 (1959).

about 75 percent mortality when directed at airbases and 95 percent when aimed at population.[8]

The above statistics represent the cost of a nuclear war when a nation is "unprepared." Here the preparedness, for the first time in U.S. history, applies to nonmilitary defense.

NONMILITARY DEFENSE

The purpose of nonmilitary defense efforts is to produce a significant reduction in the mortality estimates (as presented in the foregoing illustration) and to create conditions that make possible a recuperation of the Nation's economy.

There is no question that nonmilitary defenses can be erected which can substantially alter the character of the mortality curves presented in the illustration. The question is: Can these defenses be created at a cost that is politically feasible and nationally acceptable prior to attack?

Over the short term—while the megaton assumptions are still quite modest—I believe that relatively cheap measures can provide a reasonable degree of nonmilitary defense. To my mind this means "fall-out defense" and does not include measures capable of being effective against primary weapon effects.

As the megaton assumptions go up, then cheap measures tend to lose their effectiveness and more costly programs are required. I hesitate to assign any time scale to the increase in megatonnage since it depends not only upon Soviet strategic planning, stockpile capability, and warhead efficiency but also upon the numbers and capabilities of Soviet weapon carriers.

The facts and opinions presented in this statement indicate the necessity for a thorough reexamination of our national defense policy. An "all sword—no shield" approach to a policy of nuclear deterrence is a perilous method of achieving peace through mutual terror.

RALPH E. LAPP.

LOCAL FALLOUT RADIOACTIVITY

Ralph E. Lapp[1]

This article seeks to examine the behavior of fallout debris from the standpoint of the external radiation hazard presented by this local deposition of bomb-produced radioactivity. Sufficient time has now elapsed to permit a realistic appraisal of the radiation doses which may be projected for the fallout field over a period of years. Recent theoretical calculations and experimental data derived from the 1952 and 1954 fallouts from U.S. bomb tests facilitate the appraisal. In addition, there is a wealth of more quantitative data about fission product radioactivity and weapon technology which combine to make this fallout evaluation possible.

Official Government publications[2] and Atomic Energy Commission spokesmen specify the behavior of fission product radioactivity as obeying a $t^{-1.2}$ law. To quote Dr. Willard F. Libby:[2a]

In the ordinary atomic bomb, for each 20,000 tons of TNT equivalent, about 2 pounds of radioactive materials are produced. In these 2 pounds are some 90 different radioactive species, varying in natural lifetimes from fractions of a second to many yeas. The mixture as a whole decreases in radioactivity in such a way that for every sevenfold increase in age, the radioactivity is decreased tenfold. Thus the radioactivity by 7 hours after the explosion has decreased to one-tenth the radioactivity at 1 hour; at 49 hours (roughly 2 days) to one one-hundredth; at 2 weeks to one one-thousandth; and at 3 months to one ten-thousandth.

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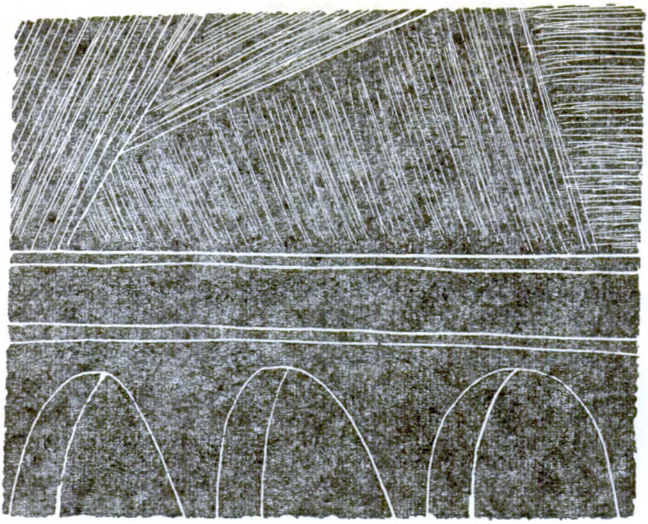
[8] Mortality estimates are for total radiation deaths but obviously include many deaths that might be attributed to primary weapon effects. They do not, however, reflect delayed effects such as those due to the breakdown of the overall economy, loss of livestock, and other food sources, or internal hazards due to radiation-contamination.

[1] Ralph E. Lapp, physicist and lecturer, has written extensively for the Bulletin and elsewhere on radiation and related matters. He is the author of several books, including "The Voyage of the Lucky Dragon."

[2] See for example, tables 9.90 and 9.119 in the Defense Department-AEC publication, "The Effects of Nuclear Weapons," Washington: Government Printing Office (1957).

[2a] Speech before the alumni reunion at the University of Chicago, June 3, 1955. Note that his earlier speech at the Washington conference of mayors (Dec. 2, 1954) is in error with regard to fallout dosage.

This is the $t^{-1.2}$ rule which is currently used by many authorities in estimating the long-term radiation dosage from fallout.



Local fallout is assumed to be a field uniformly contaminated to a level of 2 kilotons of fission products per square mile. A bomb burst producing a fission fallout of 12 megatons distributed over 6,000 square miles would produce such an average level of contamination although there would of course be regions more or less heavily contaminated depending upon the conditions at the time of the burst. The variation in the levels of fallout will be at least tenfold and even more if one considers the vagaries of micrometeorology in a large city.

CALCULATING THE ROENTGEN DOSE

Given the 2 kiloton per square mile level of contamination, the problem then resolves itself into a calculation of the radiation dose to a man in the open, assuming that the free air ionization dose is measured 3 feet above a flat, impermeable plane. A straightforward approach would be to consult the 1957 "Effects of Nuclear Weapons" publication and then to derive the dose associated with the appropriate number of megacuries of fission products. When this is done the result is that the dose rate at 1 hour after detonation is 2,500 roentgens per hour. The total or eternity dose assuming the validity of the $t^{-1.2}$ law is 12,500 r.

The above calculation follows a rather crude approach; a better estimate may be had by recourse to the following procedure. Two kilotons of fission energy correspond to the complete fission of 111 grams of uranium or to 2.86×10^{23} fissions. According to the data of R. C. Bolles and N. E. Ballou [4] this number of fissions yields 3.48×10^{19} disintegrations per second or 940 megacuries. This contrasts with a figure of 600 megacuries taken from the "Effects of Nuclear Weapons." In order to convert the fission product activity into roentgen dosage we need to know the number of photons emitted per disintegration at the time of reference and the average energy per photon. The former is 1.2 photons per disintegration and the latter is 0.92 Mev. per photon. It is important to emphasize that these numbers apply to fission products which are 1 hour old.

C. F. Miller and P. Loeb [5] list the statistical data which when applied to the above calculation yield a 1 hour dose rate of about 7,000 r/hour. This value must be considered as a maximum figure whereas that derived from data in

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[4] "Calculated Activity and Abundance of U^{235} Fission Products," USNRDL 456 (August 1956).

[5] "Ionization Rate and Photon Pulse Decay of Fission Products from the Slow Neutron Fission of U^{235}, USNRDL 247 (August 1958).

the "Effects of Nuclear Weapons" must be looked upon as a practical lower limit.

Local fallout consists of relatively heavy debris which is deposited near the site of detonation within 1 day. The fission yield curve is characterized by high yields in the vicinity of mass numbers 85 to 100 and 135 to 145. In the first group of mass numbers there are many primary fission products belonging to the elements bromine and krypton, while in the other group iodine and xenon head up the fission chains. Strontium 90, for example, has 33-second krypton as its birth predecessor; cesium 137 derives from a fission chain headed up by 22-second iodine, followed by 3.9-minute xenon. Because of their volatile or gaseous ancestry in the fireball or bomb cloud a number of the high-yield fission products are formed in finely divided particles. Some of these are so small that they are not subject to gravitational settling, and in fact they remain suspended in the earth's atmosphere for many years, providing[6] that they reach the stratosphere at the proper latitude. In any event such fission products would be depleted in the local fallout. It is difficult to allow for this depletion since it depends upon the magnitude and mode of the detonation as well as upon local meteorology.

ADDITIONAL RADIOACTIVITY

Little attention has been given to the hazards presented by radioactive products produced in nonfission reactions in the bomb itself, or in the local environment. In the case of the bomb material there is the hazard formed by the transuranic elements. For example, the irradiation of uranium^{238} with low Mev. neutrons forms neptunium 239, a 2.3-day radioelement which W. J. Heiman[7] estimates might constitute 50 percent of the residual activity a few days after a bomb detonation. The growth of Np^{239} in fallout is such that at 1 hour its activity would account for 0.5 percent of the total gamma rays; at 1 day this would rise to 23 percent, reaching a maximum of 50 percent at 4 days. Thereafter it would fall to 40 percent at 1 week, to 12 percent at 2 weeks and to less than 1 percent by 1 month. The radiation due to neptunium is by no means insignificant although it does turn out to be less than the dosage from fission products. This will become clear when we examine the rate of decay of the fission products.

At higher neutron energies, such as certain types of thermonuclear weapons produce, natural uranium undergoes an (n,2n) reaction which competes with fast fission in U^{238}. The data of R. J. Howerton[8] show that U^{238} has a fission cross section of 0.6 barn from 2 to 6 Mev., thereafter climbing to a plateau value of 1 barn for neutrons up to 14 Mev. At 6.6 Mev. there is a threshold for the (n,2n) reaction and the reaction has a cross section of 1.4 barns in the range of 10 Mev. The ready identification of U^{237} in fallout points to fast fission of U^{238} as a main energy source in high-yield megaton-class weapons.

Nuclear weapons necessarily contain significant amounts of elements (stainless steel, for example) which may add to the bomb's radioactivity. This induced activity is probably small although certain long-lived emitters such as cobalt 60 may be produced in significant amounts if small amounts of nickel and cobalt are present. P. O. Strom[9] and his associates have observed the presence of cobalt isotopes in local fallout from the Redwing series of tests in 1956. Presumably this radiocobalt originated in the bomb environment. The amounts of cobalt in ocean water are too small to account for the observed activity. It is interesting to note that the locally deposited cobalt 60 contributed largely to the 1- to 10-year activity in the Redwing sample.

Weapons burst close to the ground will produce a variety of induced activities. The hazard will depend upon the weapon yield, the neutron spectrum, the chemical composition of the substratum, and the depth of the burst. A harbor burst, for example, would induce the 14.8-hour sodium-24 activity which involves very energetic gamma radiation. There is a considerable range of induced activities possible, but it is futile to attempt any specific calculations since they would de-

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[6] See E. A. Martell, "Atmospheric Circulation and Deposition of Strontium 90 Debris," Air Force Cambridge Research Center paper (July 1958). See also W. F. Libby, "Radioactive Fallout," speech of Mar. 13, 1959.

[7] Variation of Gamma Radiation Rates for Different Elements Following an Underwater Nuclear Detonation," J. Colloid. Science, 13 (1958), p. 329.

[8] "Reaction Cross Sections of U^{238} in the Low Mev. Range," UCRL 5323 (Aug. 15, 1958).

[9] "Long-Lived Cobalt Isotopes Observed in Fallout," Science, 128 (Aug. 22, 1958), p. 417.

pend so strongly upon the factors enumerated above. In general it would be expected that they would add significantly to the fission product radioactivity but would not exceed it in radiation dosage.

Comparison of the role of fission product versus induced activity naturally depends upon the percentage contribution of fission to the total yield of the bomb. The foregoing has assumed a thermonuclear weapon in which the ratio of fission to fusion is 2 : 1. Weapons with a ratio of 1 : 10 may be thought of as relatively "clean" but this is subject to qualification, depending upon the operational conditions under which the bomb is burst. Even a 100 percent intestinally clean weapon (as defined by a test in empty space) becomes significantly dirty if the material close to the bomb is irradiated with the bomb's neutrons. This shows the fallacy of the clean bomb concept because for many military applications the detonation has to be so close to the ground that the neutron-induced activities will pose a real hazard to friend and foe alike.

THE FALLOFF OF FALLOUT

Assuming that our estimate of 7,000 roentgens per hour represents the intensity of the fission products 1 hour after detonation, let us project the dose rate into the future. Naturally at the short-lived emitters die out the activity of the fission products will fall off rapidly. This exponential decay follows a $T^{-1.2}$ law first pointed [10] out by K. Way and E. P. Wigner. If one examines the average number of photons per disintegration, it drops from a value of 1.2 at 1 hour to below 1.0 at 10 hours, rises to 1.1 at 100 hours and thereafter decreases to 0.2 at 10 years. The average photon energy for U^{235} fission products drops from 0.92 at 1 hour to 0.7 at 12 hours thereafter decreasing to 0.5 at 100 hours; it climbs to 0.6 for 9-month-old fission products, dips to 0.36 at 2 years, and levels off at 0.6 Mev. at 10 years. These fluctuations reflect the varying isotopic composition of the fission products as a function of time.

[10] "The Rate of Decay of Fission Products," Phys. Review, 73 (1948), p. 1318.

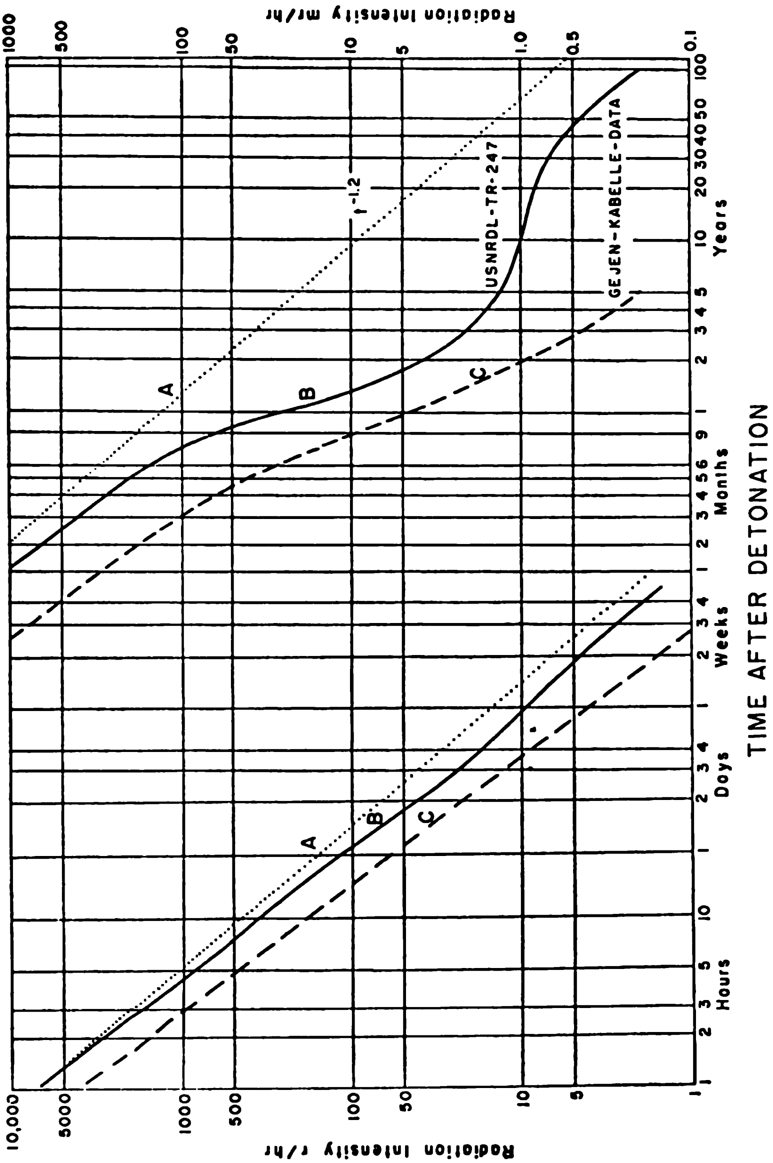

FIG. 1. FALLOUT DECAY CURVES. Ionization dose in air is calculated for a point 3 feet above the earth. Curves A and B represent theoretical values for a flat, impermeable plane.

The gamma activity of 3-year-old fission products is the sum of the contributions from three emitters each of which has a 5 to 7 percent fast-fission yield [11] in U^{238}. At the 3 years, cesium 137 is the dominant emitter with its 26-year half life it accounts for 68 percent of the residual gamma energy, 290-day cerium 144 adds 13 percent and 2.6-year Pm^{147} contributes 6 percent.

Figure 1 illustrates the theoretical decay curve for a uniform mixture of fission products corresponding to an initial 1 hour intensity of 7,000 roentgens per hour. The solid curve (B) corresponds to data taken from USNRDL-TR-247 for the ionization rate at 3 feet above an infinite plane uniformly coated with U^{235} fission products. The dotted line (A) represents the decay rate according to the $t^{-1.2}$ rule. Curve B requires some modification to adjust for the influence of certain fission products which have a different yield for fast fission in U^{238}. In general the difference between the fission products from slow fission in U^{235} and fast fission in U^{235} is an increase in yield of nuclei in the mass range 100 to 130; this is due to a lateral displacement of the low mass hump in the fission yield curve plus a raising of the bottom of the valley between the two humps.

In view of the other factors which affect the decay curve it is felt that the differences [12] due to using slow fission yields for U^{235} rather than fast fission yields for U^{238} are not as significant before as after 1 year. For time periods beyond 1 year the specific yields of certain induced activities affect the decay curve significantly.

COMPARISON WITH ENIWETOK DATA

The Atomic Energy Commission has released a number of reports [13] from which one can glean some details of the local fallout which took place in the Bravo test of March 1, 1954. We would expect such field data to reflect lower radiation intensities than the curve B plotted in figure 1 as a theoretical maximum. For shots conducted on barges at anchor in the lagoon environment there would be a fractionation of volatile and gaseous emitters with a subsequent depletion of these nuclei and their offspring in the local fallout. In addition, the data would reflect the effect of weathering and roughness of the surface. Furthermore, there would be the special induced activities peculiar to the detonation and its immediate environment.

Consideration of the field data leads the author to stipulate a realistic decay curve shown as a dashed line (C) in figure 1. A 1-hour rate of 4,000 roentgens per hour has been chosen to be equivalent to the 7,000 roentgens value deduced earlier. The immediate decay characteristics may be assumed to follow the $t^{-1.2}$ rule, this changes to a $t^{-1.3}$ relation which is assumed to be valid up to 3 weeks. Thereafter the slope of the curve is derived from gamma measurements taken in the downwind Marshall Islands.

Followup surveys of Rongelap Atoll have been carried out from March 1954, the most recent data [14] being taken August 1958. Kabelle Island, one of the northernmost in the group, has been most thoroughly monitored. Data are also available for Gejen Island, farther west than Kabelle and closer to the test site. One can make the rough estimate that Kabelle Island was subjected to a 1 kiloton per square mile fallout and Gejen had about twice this level of contamination. So far as the author is aware these constitute the only test plots for which long-term fallout decay data are available, and while they reflect conditions peculiar to tropical islands they do represent practical fallout fields of the same level as the representative field postulated here. In plotting data for these two islands on curve C, Kabelle Island gamma readings taken at 3 feet above ground level have been multiplied by 2. In addition, the author has made an adjustment for contributions of fresh fallout from Operation Redwing (1956) and Operation Hardtack I (1958). The overlays of fresh fallout tend

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[11] R. N. Keller, E. P. Steinberg, and L. E. Glendenin, Phys. Review, 94 (1954), p. 969. Also USNRDL reports TR-187 and TR-160 (1958).

[12] J. G. Cunningham, "The Mass-Yield Curve for Fission of Natural Uranium by 14 Mev. Neutrons," J. Inorg. Nuclear Chem., 5 (1957), p. 1. See also L. R. Bunney et al., "Radiochemical Studies of the Fast Neutron Fission of U^{238} and U^{235}," U.N. A/Conf. 15/P/648 (September 1958).

[13] "Radioactive Contamination of Certain Areas in the Pacific Ocean From Nuclear Tests," Editor G. Dunning (August 1957); "Some Effects of Ionizing Radiation on Human Beings," TID 5358 (July 1956); "The Shorter Term Biological Hazards of a Fallout Field," Editor G. Dunning (August 1958); also G. M. Dunning, "Criterion for Evaluating Gamma Radiation Exposures From Fallout Following Nuclear Detonations," Radiology, 66 (1956), p. 585.

[14] Dr. Gordon M. Dunning, Chief of the AEC's Radiation Effects of Weapons Branch, Division of Biology and Medicine, made these data available to the writer.

to distort the decay curve and render questionable the interpretation of data in the future (beyond 5 years).

The curve C may be represented by a $t^{-1.5}$ rule from 3 weeks to 6 months at which point there is a significantly abrupt change in slope corresponding to a $t^{-2.2}$ relation. At 6 months the curve C is an order of magnitude lower than the theoretical maximum value of curve A. At 5 years the divergence between these two curves is even more pronounced and amounts to a factor of 100. Quite clearly, this departure from a $t^{-1.2}$ dependence is of the greatest consequence for civil defense.

As explained earlier, the contribution of certain high-yield products of fast fission as well as neutron-induced activities will become important after 6 months. For example, inspection of the fission yield data tabulated[15] by S. Katcoff shows that ruthenium 106, a gamma emitter with a half life of 1 year, has a 2.7 percent yield for fast U^{238} fission but only a 0.38 percent yield in slow U^{235} fission. The actual bomb yield of Ru^{106} depends upon the effective neutron energy which one assumes and the yield may be somewhat less than 2.7 percent; nonetheless there should be about a sixfold increase in the Ru^{106} content of the Bravo fallout. At the same time one expects a very considerable (order of magnitude) increase in abundance of emitters such as 2.7 year antimony 125. This is qualitatively verified by Drs. R. F. Palumbo and F. G. Lowman[16] in an analysis of Kabelle Island soil collected July 18, 1957.

The fact that curves B and C tend to draw closer together in the 1- to 2-year period is in part due to the higher yield of U^{238} fission products and the presence of induced activities such as Fe^{55}, Mn^{54} and Co^{60}. These more than offset the depletion in Cs^{137} which occurs as a result of fractionation. Beyond 5 years one would expect the curve C to flatten out unless the Cs^{137} is severly depleted or if it is buried deep within the surface of the earth.

WEATHERING

To make any assessment of the effect of the forces of nature upon the distribution of radioactive species in the soil, it would be of the greatest value to have a good decay curve on a soil sample which has not been subjected to weathering. In lieu of such data the writer uses curve B as representing the unweathered soil situation. The radiation biology laboratory of the University of Washington dredged samples of Biijiri-Rojoa sand on November 7, 1952, about a week after the Mike-metaton shot in Operation Ivy. This sample has been kept in the laboratory and systematically followed ever since, the last measurement[17] being taken December 29, 1958. It is interesting that the last 3 years of the decay curve obey a $t^{-2.1}$ rule. The sample is depleted in Cs^{137} and enriched in Co^{60}; the decay curve shows no signs of flattening off. This may be in part due to the depletion of Cs^{137} and in part to the fact that it represents beta-decay which would be expected to show much less change of slope than the gamma curve.

Weathering is a complex interaction between the chemical species present in fallout, their varying physical form, the minerals of the soil, plus, of course, mechanical transport caused by wind, precipitation, and earth movement. One also has to consider the effect of plant and animal life as they apply to the soil surface. One would expect that the rate of descent of the various radioactive species into the soil surface would depend upon the specific type of soil; thus the Marshall Island data are taken to illustrate one weathering possibility and not as typical of all soils. Finally, it must be mentioned that U.S. experience with fallout debris has been limited, in the case of megaton bursts, to a rather special substratum characteristic of Pacific atolls and test conditions designed to minimize local fallout.[18]

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[15] "Fission Product Yields From U. Th. and Pu," Nucleonics. 16 (1958). 78.

[16] "The Occurrence of Antimony 125, Europium 155, Iron 55, and Other Radionuclides in Rongelap Atoll Soil," UWFL–56 (April 1958).

[17] The author is indebted to Dr. K. Bonham for supplying these data, supplementing the results reported in UWFL–53 "Radioactivity of Invertebrates and Other Organisms at Eniwetok Atoll During 1954–55" (Jan. 6. 1958).

[18] N. H. Farlow and W. R. Schell, "Physical, Chemical, and Radiological Properties of Slurry Particulate Fallout Collected During Operation Redwing," USNRDL TR 170. See also C. E. Adams and J. D. O'Connor, "Nature of Individual Radioactive Particles—Operation Redwing," USNRDL TR 208 (December 1957).

Core samples[19] taken on Gejen Island in 1955 showed the following beta activity:

Soil layer	1st	2d	3d	4th	5th	6th inch
Activity	37,000	37,000	8,000	4,000	4,400	3,400 betas/min/gm

Data taken from soil on other islands indicate a similar soak-in of fission debris down to a depth of 6 to 8 inches. The 1956 resurvey of Gejen soil (table 18 in the reference 18) shows that the residual activity concentrates in the upper inch of soil. Although the data on soil uptake of fission debris are not firm, it appears that, at least in the case of Marshall Island soil, weathering is not severely cumulative in effect. If we compare curves B and C without making allowance for terrain effects, then up to 2 years there is a difference of a factor of about four. A British estimate[20] assumes a "protection factor of three" for British soil contaminated with stratospheric fallout.

Weathering effects beyond 2 years will depend very critically upon the nature of the radioelements which then predominate in the fallout debris. And as we have seen, this is likely to be quite variable. For a normal mixture of fission products, the long-term radiation dosage would depend upon the weathering of cesium in the soil. Cesium should be quickly fixed[21] in the upper soil surface, probably in the first inch. Fixation is assumed to be proportional to the colloidal content of the soil and would be greatest in clay soils and least in sandy loams. Radiocesium would be expected to resist leaching even under conditions of heavy (tropical) rainfall.

THE GAMMA HAZARD

The foregoing discussion makes it appear reasonable to use curve C in estimating the radiation dosage to which people might be exposed from a representative fallout field corresponding to a 1-hour level of 4,000 roentgens per hour. We make use of a $t^{-1.2}$ relation up to 3 weeks and a $t^{-1.6}$ up to 3 months, Previous articles in the Bulletin have already spelled out the nature of the fallout radiation dosages during the first day, so these data will not be repeated. Beginning with the second day table I lists the gamma doses for various time intervals.

Table I

Time interval:	*Gamma dose, roentgens*	Time interval—Continued	*Gamma dose, roentgens*
2d day	950	2d month	220
3d day	500	3d month	100
4th day	300	4th month	60
5th day	225	5th month	40
6th day	175	6th month	25
7th day	120	6th to 12th month	60
2d week	535	2d year	20
3d week	285	3d year	6
4th week	140	4th year	3

Use of the $t^{-1.2}$ law involves a great overestimate of the actual radiation hazard over long periods of time. For example, the 1 to 4 years dose is 27 times higher than that represented by curve C. Since the dose beyond 4 years is very cesium-sensitive, any estimate must depend upon assumptions about the degree of fractionation of Cs^{137} in the fallout and degree of weathering. If one assumes no fractionation and a uniform deposit over a hard, flat plane then the level corresponding to 400 curies of Cs^{137} per square miles would produce a dose of 380 roentgens over a period of 50 years. No experimental data

[19] From table 15 of AEC publication, "Radioactive Contamination of Certain Areas in the Pacific Ocean From Nuclear Tests," Editor G. Dunning (August 1957).
[20] N. G. Stewart, R. N. Crooks, and E. M. R. Fisher, "The Radiological Dose to Persons in the United Kingdom Due to Debris From Nuclear Test Explosions Prior to January 1956," AERE HP/R 2017 (1957).
[21] W. Langham and E. C. Anderson, "Entry of Radioactive Fallout Into the Biosphere and Man," Bull. Swiss Acad. Med. Sci. 14 (1958), p. 434.

extend much beyond 5 years but if one assumes that curve C flattens off and reaches a value close to 0.1 milliroentgens per hour at 50 years the integrated dose would be about 50 roentgens.

The application of these data to the problem of survival in time of nuclear war is discussed in the accompanying article.

FALLOUT AND HOME DEFENSE

Ralph E. Lapp

Soviet successes in the nuclear weapons and missiles field together with an unremitting arms race call for a new look at the problem of home defense. This is all the more necessary because of a general prevailing impression that civil defense is hopeless.

There is no use in avoiding this blunt statement of the issue at this stage of world affairs. Moreover, the rapid succession of mounting hazards—the megaton, fallout, and ballistic missiles—forms a terrible triad. Civil defense planners have never been able to keep step with the tempo of arms development and very often they were hamstrung in their efforts to obtain the necessary planning information from the Defense Department and the Atomic Energy Commission.

Excellent studies of the civil defense problem were made available in 1958, notably the testimony[1] of Dr. Ellis A. Johnson, director of the operations research office, Johns Hopkins University, and the Rand report,[2] the gist of which was presented by Dr. Herman Kahn in the January Bulletin. These analyses deserve careful consideration because they point out the profound interrelation of population survival and sound defense policy; furthermore they maintain that an effective civil defense is possible.

The triple impact of megatons, fallout, and missiles convinces most Americans that their lot will be a hopeless one should the United States be subjected to a nuclear attack. The Oro and Rand assertions to the contrary have not as yet made an appreciable dent in the public attitude, certainly not in congressional attitudes. The reshuffle of the Federal Civil Defense Administration into the new Office of Civil Defense Mobilization has made little apparent change in the administration's handling of the civil defense issue. Civil defense is still in the research and development and planning stage. And it is now almost 14 years since Hiroshima.

No one in Washington expects that OCDM will be energized with a massive infusion of funds to support a national civil defense program on the scale of multibillion dollar appropriations. The Congress continues to be highly skeptical of any increases in civil defense appropriations, and the White House has given no indications of asking for a budget sufficient to finance a national shelter program.

I feel that under these conditions, the problem of civil defense transforms to home defense, and the citizen must look to his own security. This would seem to be in line with the views of Civil Defense Administrator, Gov. Leo Hoegh, who answered in reply to a question about shelter construction[3]: "Of course, we have not advocated a Federal construction program. We advocate this, the self-help program. That's nothing new. For instance, back in the Indian age our forebears, when they built their homes, also, provided a fortress. In 1958 the American people in their own home should provide themselves protection from radioactive fallout. We give the guidance and the direction."

Our forebears were confronted with the challenge of the bow and arrow and the tomahawk. Today we face the swifter-than-sound ICBM, the incomprehensible megaton, and the unsensed threat of radioactive fallout. This disparity is so immense that the average person is overwhelmed; he looks to his Government for guidance, and he is advised to "do it himself."

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[1] Pp. 241–269 of the Holifield civil defense hearings, House Government Operations Committee, May 5, 1958.

[2] "Report on a Study of Nonmilitary Defense," Rand Corp. Report R–322–RC (July 1, 1958).

[3] Transcript of "Meet the Press" television program of Sept. 7, 1958.

MISSILE WARHEADS

Mr. Khrushchev has implied that the Soviets have a compact nuclear warhead with a 5-megaton explosive equivalent. It is assumed that this nuclear explosive is compact enough to fit into an ICBM nose cone and that it is about 1.5 tons in weight. This constitutes a very considerable accomplishment in weapon development. Little is known about the actual weight of the Soviet bomb package, but analysis[4] of the October 1958 tests shows that the Soviets released about 20 megatons (strontium equivalent) of fission energy to the stratosphere. It would seem prudent to assume that the Soviets have developed a 5-megaton ICBM warhead. The radio chemical data available to the author suggest that compactness in this missile warhead has been achieved at some expense in terms of nuclear material. The burning of cheap U^{238} involves a weight disadvantage in missiles but is useful in high-yield, air-dropped bombs such as the 20-megaton weapons carried by the U.S. strategic bomber, the B-52.

Continued nuclear testing should result in an early doubling of megatonnage in missile warheads and with increased development of rocket fuels, warheads of 20 megatons must be anticipated. By the same token bomber weapons may be doubled and tripled in power, i.e., 40 and 60 megatons. It is understood that the Strategic Air Command is thinking in such terms for B-52 and B-58 carried bombs.

With the development of megathrust propulsion plants and possibly with the perfection of nuclear-powered ramjets the transportation of 100-megaton bombs appears feasible, although this is further in the future. The military worth of such high-yield weapons is arguable, depending upon what purposes are involved in the military applications. If the weapons are meant for blast applications for the reduction of strategic targets of "hardened" construction, then blast pressures of the order of 100 pounds per square inch are required. A 1-megaton warhead, such as might be developed for a Polaris missile, would produce 100 pounds per square inch at five-eighths mile; a 5-megaton warhead (present Soviet ICBM capability) would extend this blast to 1 mile; a 20-megaton SAC bomb would reach to 1.7 miles, and a super 100-megaton bomb would range out to 3 miles.

Given a missile accuracy such that 50 percent of the warheads land within a circle of 5- to 10-mile radius it is obvious that huge numbers of Polaris-type missiles would be required to knock out a hardened missile site and very considerable numbers of 5-megaton missiles would also be required. On the other hand, 20-megaton bombs launched from short range by B-52's or B-58's with greater accuracy could be very effective; this is a prime reason why the U.S. Air Force believes that bombers will still be in business 5 to 10 years from now.

Judging from U.S. bomber capabilities, our strategic retaliation against Soviet attack would involve a 1-day level of attack in excess of 10,000 megatons. Actual on-target deliveries might reduce this considerably depending upon the alert status of SAC bases and the nature of Soviet defenses. It is not clear why such a high level of attack is contemplated on a second blow basis since in making the first strike Soviet military installations would presumably have fulfilled their prime role. Adm. Arleigh A. Burke, Chief of Naval Operations, has questioned the strategic mission of the Air Force in a recent speech[5] in which he stated: "* * * We recognize that in general nuclear war missile forces can no longer attempt to destroy their enemy's counterpart without destroying the corporate body of the enemy state itself, provided all these forces are stationed within the heart of the homeland." This raises the fundamental issue of the wisdom of locating prime strategic bases within continental United States. The level of enemy attack upon the United States will depend upon the number and nature of U.S. strategic bases; thus our military leaders may be making profoundly wrong decisions in locating hardened missile sites within the U.S. borders. Each hardened site may cause the enemy to allocate immense megatonnage to its destruction but the fallout from these bombs will inevitably spill out over the U.S. population and food areas.

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[4] Speech of Dr. W. F. Libby, Mar. 13, 1959. The author has also received radio chemical analyses from Japanese scientists.

[5] Given before the Chamber of Commerce, Charleston, S.C., Feb. 20, 1959.

The foregoing suggests that "the megaton assumptions" for the United States meaning the commitment of bombs to U.S. targets may vary within wide limits and may actually be determined by our own decisions. The present 30-odd strategic bases within the continental United States are nonhardened or "soft" and it appears that Russia could be forced to commit a minimum of 1,000 megatons to these targets. Additional targets would double or triple this megatonnage during the time span of the next 3 years. It is within the framework of this assumption that the author proposes to view the civil defense problem. Obviously, the feasibility of civil defense depends very critically upon the megaton assumptions because a decade from now 3,000 megatons may be a small fraction of the Soviet strategic capability.

FALLOUT AND SURVIVAL

The current status of our civil defense offers little hope that the primary effects of thermonuclear weapons can be minimized to any significant degree. The protective construction necessary to reduce the sledge-hammer effect of the megaton blast on cities involves a degree of metropolitan surgery which is deemed unattainable now. When there was time our cities were not made less vulnerable by dispersion, and now that there is little time the metropolitan areas cannot be hardened like a missile site.

However, the random sprawl of our cities coupled with the inherent inaccuracy of ballistic missiles makes it probable that very large chunks of our metropolitan areas will remain outside the zones of heavy blast damage. Populationwise, the situation is even more favorable since ground zero is equally probable for downtown and the suburbs.

As I see the problem for the average American, he can't do very much about combating the primary effects of megaton weapons; only the rara avis will go to the trouble and expense of building a blast shelter. However, the big problem once the impact of the blast-heat ceases to be felt upon the striken community is protection against radioactive fallout. This problem centers upon the family home, and it is for this reason that the term "home defense" applies.

Vast areas remote from the actual bomb bursts will be subjected to lethal radioactive fallout; in some cases where there are multiple bursts and strong winds the lethal distance may extend to 500 miles from ground zero. Areas downwind of prime strategic targets will fall in this category. Thus the true lethal potential of a nuclear attack derives from the fallout hazard. Primary lethality of megaton weapons centers upon an area 20 to 40 times smaller than that subject to lethal fallout.

I believe that the average American's understanding of radioactive fallout is pitifully inadequate. Judging from contacts with thousands of people during the past 5 years, I arrive at the conclusion that there is a deep-rooted feeling that there is no way to escape death from fallout. It is for this reason that I reexamined the fallout radiation hazard (see previous article).

The fallout field which has been assumed seems realistic, i.e., 2 kilotons of fission debris per square mile corresponding to an actual rate of 4,000 roentgens per hour 1 hour after the bomb burst. The first day radiation exposure depends very critically upon the time of fallout. It may require only 1 hour for complete fallout close to the target or as much as 18 hours farther downwind.[6] Reliable data on megaton-class fallout are fragmentary, but Dr. Paul C. Tompkins, scientific director of the U.S. Naval Radiological Defense Laboratory, testified before the Holifield Civil Defense Subcommittee[7] that "the major residual radiation threat does not occur within range of physical damage." It was stated that peak radioactivity never occurs at the crater but about 50 to 75 miles downwind.

The first day fallout is illustrated by the following schedule of roentgen doses:

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[6] W. W. Kellogg, R. R. Rapp, and S. M. Greenfield, "Close-In Fallout," J. Meteorology, 14 (1957), p. 1.

[7] Pp. 209–210 of reference 1 (May 2, 1958). It appears that these data focus upon Pacific tests where the substratum is largely water. Very little data exists for the case of megaton bombs burst on continental surfaces.

Table I

Time interval:	Gamma dose, roentgens
1 to 2 hours	2,500
2 to 3 hours	1,250
3 to 4 hours	800
4 to 5 hours	550
5 to 10 hours	1,500
10 to 24 hours	1,550

Each hour that the fallout is delayed reduces the first-day integrated dose by hundreds and thousands of roentgens. If we assume an effective time of fallout as 3 hours, the first-day exposure to a person standing in the open is about 4,000 roentgens. Some analysts[8] believe that a nuclear attack upon the United States would produce areas in the Northeast where the 2-day radiation dose would exceed 10,000 roentgens. It is estimated that the variable fallout patterns would overlap to blanket many States in a coat of radioactive contamination.

RADIATION PROTECTION

The fundamental rule for survival in time of fallout or suspected fallout is below-ground shelter. This evasion action must take priority over all other activities during the first few days following the outbreak of nuclear war.

Since it is doubtful if many American will possess prebuilt radiation shelters, the do-it-yourself approach must be followed. The hours of grace before lethal fallout may reach the earth allow time for last-minute improvisation of radiation shelters. The ordinary basement provides a ten-fold to twenty-fold reduction in the radiation dose. Further reduction can be attained by lying prone in one corner of the basement but for many regions it will be necessary to provide additional below-ground shelter. This can be provided by use of the foxhole principle or by shielding with some dense material. A tunnel dug in the cellar wall would provide excellent protection. Stacking up bags of coal, sand, or containers of water in a corner of the basement would also reduce the radiation dose.

A committee of the National Academy of Sciences is pondering the problem of setting up a schedule of "allowable" radiation doses for a nuclear catastrophe but the final report is not expected for several months. Presumably, 25 roentgens might be stipulated for the first day and 100 roentgens for the first week. The shelter protection factor required to keep the dose below 25 roentgens during the first day would range from 100 to 500 for most areas. Using table I on page 186, it is seen that this protection factor drops rapidly during the first week permitting the holed-up survivors to emerge from cramped quarters after 2 or 3 days and enjoy more freedom of movement in the basement.

During the third day the external radiation would drop to 10 roentgens per hour and limited excursions within buildings would be possible for adults. At the end of 1 week the the outdoor level would drop to 4 roentgens per hour in open fields (it might build up to higher values in built-up areas where the fallout debris naturally concentrates), and limited above-surface excursions could be made.

DECONTAMINATION

Natural decontamination of building materials may occur as a result of weathering processes.[10] Actual tests[11] carried out at the Nevada Proving Grounds showed that a 2-inch rainfall following fallout reduced the indoors radiation dose to one-tenth to one-twentieth the dose measured in an adjoining field. The radiation level just above the floor was one-tenth that at a height of 7 feet inside the house.

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[8] For example, Dr. Ellis A. Johnson in his speech before the Washington Philosophical Society, Washington, D.C. (Mar. 28, 1959).

[10] See L. Machta and K. M. Nagler, "Meteorology Fallout and Weathering," p. 8 in AEC publication, "The Shorter-Term Biological Hazards of a Fallout Field" (1958).

[11] R. T. Graveson, "Radiation Protection Within a Standard Housing Structure," NYO-4714 (November 1956).

F. P. Cowan[12] has investigated the buildup of fallout on construction materials and he has found that smooth-surfaced materials such as aluminum accumulate the least fallout and yield most quickly to decontamination, whereas asphalt and asbestos shingles hold the fallout more tenaciously.

After 1 week a properly indoctrinated householder might attempt to reduce the contamination on the roof. A twentyfold reduction of the roof contamination (as compared with open field levels) seems feasible. Since the roof contamination contributes as much radiation dose to the basement as the skyshine of radiation from adjoining land[13] an overall tenfold dose reduction for basement dwellers is possible.

Decontamination of ground areas and pavements will involve an organized effort and substantial equipment. The U.S. Navy has had practical experience in radiological decontamination as a result of the Bikini bomb tests in 1946. Data[14] from the U.S. Naval Radiological Defense Laboratory show that firehosing of asphalt surfaces contaminated with dry fallout can reduce the level of radioactivity thirtyfold.

In the absence of extensive decontamination it would appear wise to live very cautiously during the 1-week to 1-month period after attack. The second week dose of about 500 roentgens should be kept below 20 roentgens and preferably below 10 roentgens. The same rule applies to the third week. The 140 roentgen dose which would be accumulated by full above ground exposure during the fourth week can be cut to 7 roentgens by an overall reduction factor of 20; this still requires basement living unless decontamination has been effective.

BEYOND 1 MONTH

Once the challenge of the first month of postattack living has been met, the radiation hazards in the following months can be put into manageable proportions by cautious living. At about the time the outdoor levels will be about 10 roentgens per day—still too high for long-term above-ground movement. However, local decontamination and restricted movement plus indoor living as much as possible should make it possible to keep the radiation dose below 10 roentgens for the second month. Thereafter the radiation exposures call for caution but the problem is clearly no longer an acute one.

After 4 months the maximum 24-hour dose for a man in the open would be about 1 roentgens although it might be 10 times less in a decontaminated area. At the end of 1 year an untouched area should exhibit about 0.1 roentgens per day and the total dose in the second year after attack would be about 20 roentgens so that return to ordinary life as far as the external hazard is concerned would be indicated. For people who had accumulated 100 roentgens in the first year an additional 5 roentgens in the second year (allowing for shielding) would not constitute undue risk. Since the impact of the attack might replace our industrial economy with a colonial type of existence millions of people would have to till the soil, this would involve greater exposure but it would not be prohibitive.

These conclusions apply to the radiation field specified by a fallout of 2 kilotons of fission products per square mile. It would seem that this kind of a fallout field is a reasonable projection through the early sixties.

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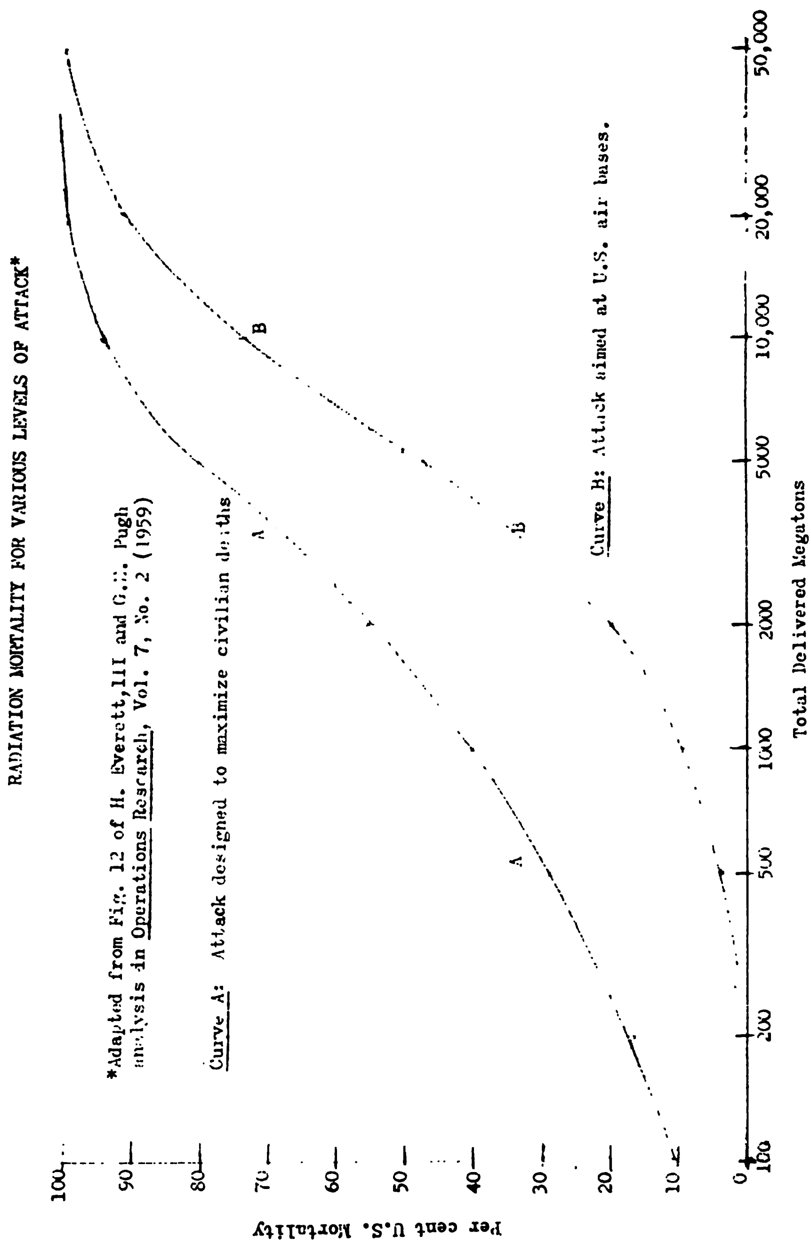
[12] "The Accumulation of Radioactive Fallout on Typical Materials of Construction," BNL–497 (March 1958).

[13] J. A. Auxier et al., "Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources," CEX–58.1 (Jan. 19, 1959). See also M. J. Berger and J. C. Lamkin, "Simple Calculations of Gamma-Ray Penetration Into Shelters: Contribution of Skyshine and Roof Contamination," Report NBS–2827 (February 1958).

[14] "Radiological Recovery of Fixed Military Installations," USNRDL report dated August 1958.


RADIATION MORTALITY FOR VARIOUS LEVELS OF ATTACK*
*Adapted from Fig. 12 of H. Everett, III and G.E. Pugh analysis in Operations Research, Vol. 7, No. 2 (1959)
Curve A: Attack designed to maximize civilian deaths
Curve B: Attack aimed at U.S. air bases.
A
B
A
B
Per cent U.S. Mortality
0
10
20
30
40
50
60
70
80
90
100
Total Delivered Megatons
100
200
500
1000
2000
5000
10,000
20,000
50,000

Representative HOLIFIELD. With this note we will announce the afternoon session. We have concluded the panel. The afternoon session will begin with the investigation of the biological effects of the hypothetical war. We are going to have a very interesting session because we are going into this heat and light, the thermal burns and flash effects. There has been very little of that declassified heretofore and brought to the public's attention, and I think this will be a very informative afternoon.

We will also go into the acute effects of radiation as well as the effects of protracted exposure. We have experts here that will testify on this point.

The committee stands adjourned until 2 o'clock.

(Whereupon, at 12:30 p.m. the committee was recessed, to reconvene at 2 p.m. the same day.)

AFTERNOON SESSION

Representative HOLIFIELD. The committee will be in order.

This afternoon we will explore the effect of heat and light, thermal burns and flash effects on the eyes and other biological effects.

As our first witness we will have Dr. William T. Ham, Department of Biophysics of the Medical College of Virginia. He is a consultant of the Atomic Bomb Casualty Committee of the National Academy of Sciences and is author of numerous articles on radiobiological and thermal injury and has participated in the nuclear weapons tests. So he speaks from a standpoint of not only academic knowledge but of personal and clinical experience.

Dr. Ham, will you please come forward. Dr. George Mixter is the responsible person assisting him. He is from Harvard College and medical school. He was the responsible investigator on a series of flash burn studies for the Atomic Energy Commission. He has many other different attainments.

In addition we have Comdr. Charles H. Fugitt, from the U.S. Navy. He was educated at George Washington University and Massachusetts Institute of Technology and a few good universities out in my State of California. He has published papers on thermodynamics and special properties of biological materials.

Their biographies will be a part of the record.

STATEMENTS OF WILLIAM T. HAM, JR.,[1] DEPARTMENT OF BIOPHYSICS, MEDICAL COLLEGE OF VIRGINIA; GEORGE MIXTER, JR.,[2] ASSOCIATE PROFESSOR OF SURGERY, NEW YORK UNIVERSITY POSTGRADUATE SCHOOL OF MEDICINE; AND COMDR. CHARLES H. FUGITT,[3] U.S. NAVY, RADIATION CONSULTANT

Representative HOLIFIELD. We are glad to have you three gentlemen here, and Dr. Ham, will you please take the lead in the presentation.

Dr. HAM. Mr. Holifield and members of the committee, I feel it a very responsible position in which I am placed in trying to present to you gentlemen the thermal effects of radiation from 1- to 10-megaton weapons. In a certain sense, in the discussion so far, I cannot help but feel that the cart has been put before the horse in the sense that we have got to survive first before we can be subjected to the effects of fallout.

I should like to ask the indulgence of the committee in being able to refer to my two colleagues on questions if they come up during the testimony which might be more appropriately answered by them than by me.

Representative HOLIFIELD. This is in order.

Dr. HAM. Thank you, sir. With that I will read my text or testimony, and if there are questions I will do my best to answer them.

THERMAL INJURY FROM NUCLEAR WEAPONS

The use of fire as a weapon in warfare has been traditional since the earliest historical times. Burn injury is painfully familiar to all of us. However, the advent of nuclear weapons in modern warfare has introduced thermal injury on a scale outside our previous experience. The sudden production of severe burns on a mass casualty basis pre-

[1] Dr. Ham was educated at the University of Virginia, receiving the doctor of philosophy degree in physics. He has been on the faculty of Columbia University and the University of Virginia, where he also worked on special investigations for the OSRD and Manhattan project. He served in the U.S. Marine Corps in the Pacific during World War II as a radar officer and has been professor and chairman of the Department of Biophysics and Biometry at the Medical College of Virginia since 1953. Dr. Ham is a fellow of the American Physical Society and several other scientific societies. He is a consultant of the Atomic Bomb Casualty Committee of the National Academy of Sciences—National Research Council, the Oak Ridge National Laboratory, and the Army Medical Service Graduate School. He is the author of numerous articles on radiobiology and thermal injury, and has participated in nuclear weapons tests.

[2] Dr. Mixter was educated at Harvard College and Harvard Medical School, receiving the degree of doctor of medicine, and has been certified by the American Board of Surgery. He served with the U.S. Marines in the Pacific during World War II as a medical officer. He has been a research fellow in surgery at the Boston University School of Medicine and chief resident in surgery at Massachusetts Memorial Hospital. He has also held other research fellowships in medical and surgical research at Western Reserve University and Cleveland City Hospital. Dr. Mixter has been on the faculty of the University of Rochester School of Medicine, and was the responsible investigator on a series of flash burn studies for the Atomic Energy Commission. He is currently associate professor of surgery at New York University Post-Graduate Medical School and visiting surgeon at Bellevue Hospital, and attending surgeon at University Hospital and Manhattan Veterans Hospital. He is also consultant in biomedicine to the Navy Materials Laboratory, and has published many papers on surgery and thermal injury.

[3] Commander Fugitt was educated at the George Washington University, the Massachusetts Institute of Technology, and the University of California at Berkeley, receiving the doctor of philosophy degree from the latter institution in biophysics. He has been a teaching fellow and a member of the Laboratory for Nuclear Science at the Massachusetts Institute of Technology, and Chief of the Biophysics Division of the Aviation Medical Acceleration Laboratory at the Naval Air Development Center. He has also participated in nuclear weapons tests in the Pacific and in Nevada. Concurrent with his present military assignment to the Defense Atomic Support Agency, he has been a professional lecturer in the School of Medicine of the George Washington University. Commander Fugitt has published papers on the thermodynamic and spectral properties of biological materials.

sents a medical problem of staggering proportions. The Cocoanut Grove disaster in 1942, involving about 500 burn casualties, severely taxed the medical facilities of Boston. At Hiroshima, thermal injury overwhelmed the medical facilities of the city. A few passages at random from Hiroshima Diary, the journal of a Japanese physician, will convince anyone as to the seriousness of the burn problem after nuclear attack. When one considers that the Hiroshima drop was roughly 20 KT, whereas, we are discussing today weapons in the 1–10 MT range, the catastrophic nature of the problem becomes obvious.

The treatment of severe thermal injury on areas in excess of 25 percent of the whole body represents a grave medical problem even in a modern hospital and under the best of circumstances. For mass burn casualties under field conditions the situation takes on overwhelming proportions. An unwarned urban population caught out of doors during nuclear attack would suffer almost complete annihilation from blast and thermal energy out to a radius of many miles from ground zero. While it is feasible to avoid the prompt thermal flash by taking cover, it is not so evident how to avoid the secondary effects of the burning environment which develops soon after the burst. It is probable that burns from secondary fires engendered by the bomb would represent a major proportion of the casualties even for a population which had received warning of imminent attack. From the medical point of view, a burn is a burn, whether received as a flash burn from the initial thermal burst or, at a later time, from the burning environment.

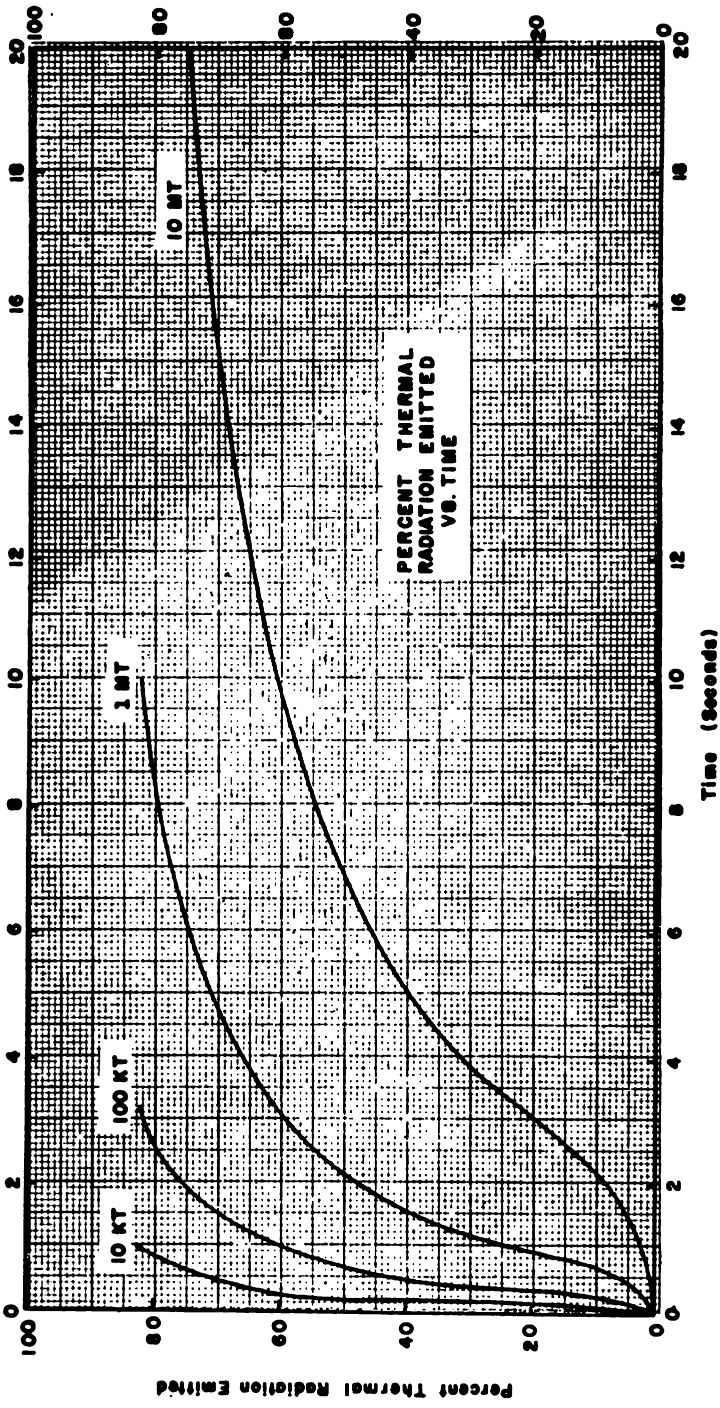
In order to save a little time and because some of this testimony regarding the physical effects of the nuclear weapon has already been covered, I am going to skip a small portion of this page 2, if I may, sir, and begin with the last sentence before the second paragraph.

The second pulse of thermal radiation reaches maximum radiant power in about 1 second for a 1-MT weapon. This pulse radiates thermal energy in the visible region of the spectrum and is responsible for the severe thermal effects accompanying a nuclear explosion.

For a 1-MT weapon, the ball of fire attains a diameter of about 6,300 feet in 2 seconds after the detonation; the maximum diameter of 7,200 feet or 1⅓ miles occurs at approximately 10 seconds. The fireball from a 10-MT weapon attains a maximum diameter of about 3 miles in about 40 seconds. It takes about 1 second for a 1-MT weapon to reach maximum radiant power, i.e., maximum burning power during the second radiant pulse; a 10-MT burst requires about 3 seconds to reach maximum radiant output. In figure I, the percentage of total thermal radiation emitted is plotted against time for 1- and 10-MT weapons.

Also, we have included a 100-kiloton weapon.

FIGURE I


PERCENT THERMAL
RADIATION EMITTED
VS. TIME
10 KT
100 KT
1 MT
10 MT
Time (Seconds)
Percent Thermal Radiation Emitted
0
2
4
6
8
10
12
14
16
18
20
0
20
40
60
80
100

For example, about 60 percent of the thermal dose from a 1-MT weapon is delivered within 3 seconds, the maximum rate of delivery occurring at 1 second after detonation. A 10-MT burst requires about 10 seconds to deliver 60 percent of the total thermal dose and the maximum rate of delivery occurs at approximately 3 seconds. These curves illustrate a most important factor, namely, the larger the weapon, the greater the time available for evasive action. However, evasive tactics must be exercised before 60 percent of the total energy has been delivered. For personnel well indoctrinated in evasive tactics, this could mean the difference between a moderate sunburn and severe thermal injury.

The amount of thermal energy falling upon unit area (usually expressed as calories per square centimeter or cal./cm.^{2}) depends upon the thermal yield of the weapon, the distance from the explosion, and to some extent upon the state of the atmosphere. Weather conditions at the time of burst may have a pronounced effect upon the extent of thermal damage. This is a very complex subject which can only be mentioned here. Light rays are attenuated by two physical processes—absorption and scattering. Absorption is most effective for the short wavelengths and it is because of molecular absorption that UV light is attenuated markedly within a short distance of the explosion. Scattering or diversion of the rays from their original path occurs with radiation of all wavelengths. Molecular scattering by air and water vapor is not so important as scattering resulting from the reflection and bending of light rays by particles of dust, smoke, and fog present in the atmosphere. If the air contains a moderately large number of particles the amount of radiation transmitted directly will be less than for a clear atmosphere, but this decrease is partly compensated for by the phenomenon of multiple scattering, whereby subsequent scattering of already scattered light results in return of the light to its original objective. In this presentation, a transmissivity of 0.5 has been assumed for radiation from the fireball. Numerous experiments in Nevada and the Pacific have indicated that a 50-percent transmission factor for radiation in the visible and infrared region represents a fair average figure based on experience in the field under varied meteorological conditions.

The development of a ball of fire is a phenomenon associated with nuclear explosions within the earth's atmosphere. Nuclear weapons detonated at high altitudes where the atmosphere is tenuous or rare do not produce a fireball of well-defined dimensions; i.e., the fireball from a nuclear weapon is strictly dependent upon the density of the atmosphere surrounding the point of burst. This has important consequences in trying to assess thermal effects from bursts at high altitudes.

3. BIOLOGICAL EFFECTS: FLASH BURNS TO UNPROTECTED SKIN

Experiments in the laboratory and in the field have established criteria for assessing the degree of thermal damage to be expected for doses of thermal radiation delivered to human tissue within specified time limits. Medical diagnosis usually recognizes three grades of thermal injury; first, second, and third degree injury in ascending

order of severity. A first-degree burn corresponds to a moderate sunburn or erythema. Such damage, while quite painful, is reparable with time and requires no special treatment beyond the relief of pain. The second-degree burn involves the skin thickness down to and including portions of the dermis. A characteristic feature of second-degree burns is the formation of blisters. Many physicians distinguish between moderate and severe second-degree burns, basing their diagnosis on the estimated depth of destruction. The second-degree burn is extremely painful but also reparable with time. Infection usually occurs since the protective barrier of the epidermis has been pierced, leaving the tissues open to infective pathogens. Given time and opportunity to combat infection, the majority of second-degree wounds heal without undue aftereffect though permanent pigmentation changes may persist. The third-degree burn involves complete destruction of the whole skin thickness. Except for very small area burns these wounds are not reparable with time but require skin grafting in all cases. Infection is invariably present. Paradoxically, the third-degree burn is not as painful as the second-degree burn because the nerve endings have been destroyed; yet third-degree burns to more than 25 percent of the human body area represent catastrophic injury.

A pulse of radiant energy incident on tissue produces serious injury if the temperature of the tissue remains above a certain value for a critical length of time. Obviously, the rate at which the thermal energy is delivered plays an important role in determining skin temperature since the skin can dissipate heat fairly effectively if given time. For example, experiments on human white volunteers have shown that a thermal dose of 3 cal./cm.^{2} delivered in 0.5 second produces well defined second-degree burns, and 5 cal./cm.^{2} produces a third-degree burn. Similar experiments on Negro volunteers indicate that the thermal exposure required to produce first-degree, second-degree, and third-degree burns are reduced by about one-third. Thus, skin pigmentation also plays an important role in assessing burn thresholds because it determines the amount of radiant energy which is absorbed or reflected by the skin.

Senator ANDERSON. I want to be sure I understand. Do I understand that the Negro volunteers got their burns with a third less exposure?

Dr. HAM. Yes, that is essentially correct, sir. In other words, about one-third less calories per square centimeter of energy delivered under the same circumstances will produce the same type of injury in the Negro race as in the white race.

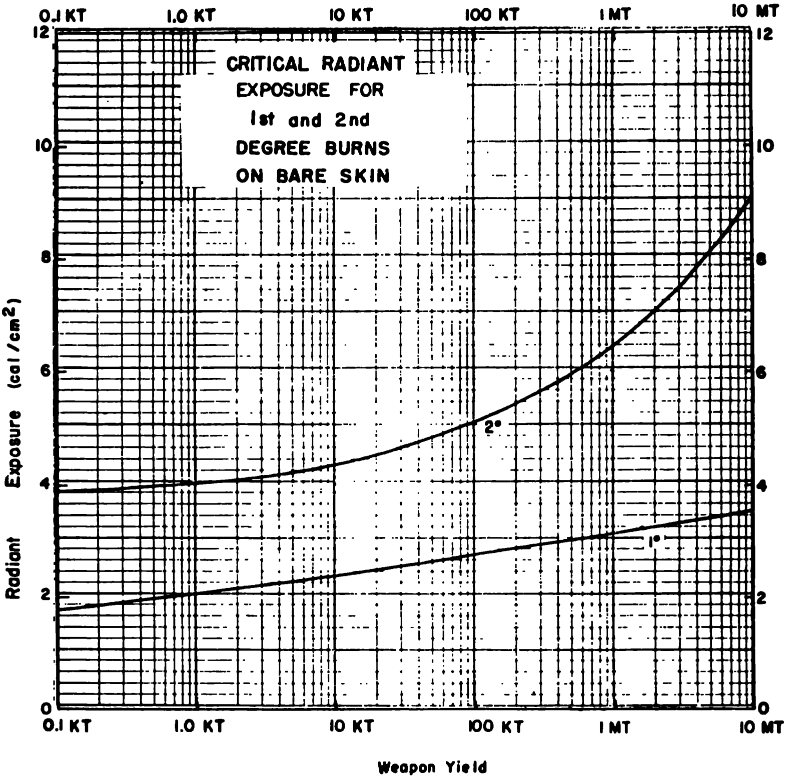
In other words, they are more susceptible to flash burns by about one-third, sir.

Nuclear weapons of 10–100 KT deliver at least 60 percent of the total thermal radiation from the second radiant pulse in less than 0.5 second. Weapons in the 1–10 MT range, while producing more thermal energy over a greater radius from the burst than weapons of 100 KT or less, deliver this thermal energy at a much slower rate than the small weapons. Thus, for equal thermal doses incident on tissue, the

small weapons are more effective in producing thermal injury because the large weapons require anywhere from 5 to 15 seconds to deliver 60 percent of the thermal dose.

In figure II, the thermal dose estimated to produce first-degree and second-degree burns is plotted against weapon yield. For example, it

FIGURE II



requires 7–9 cal./cm.² to produce second-degree burns from a 10-MT weapon. Contrast this with a dose of 4 or 5 cal./cm.² for a 100-KT weapon.

Any comfort derived from a comparison of the thermal effectiveness of small versus large weapons is dispelled when the magnitude and radius of effect of the large weapons is taken into account. Figure III presents data for a 10-MT drop on New York City. The diameter of the fireball alone is about 3 miles, and there would be complete destruction within this range. Flash burns produced on unprotected skin (generally the face, hands, and legs) by the second radiant pulse from the weapon, of this magnitude are avoidable by forewarning or by evasive action. People indoors or in shelters would not receive flash burns. Almost any opaque substance will afford protection. Persons unable to take evasive action would sustain second-degree

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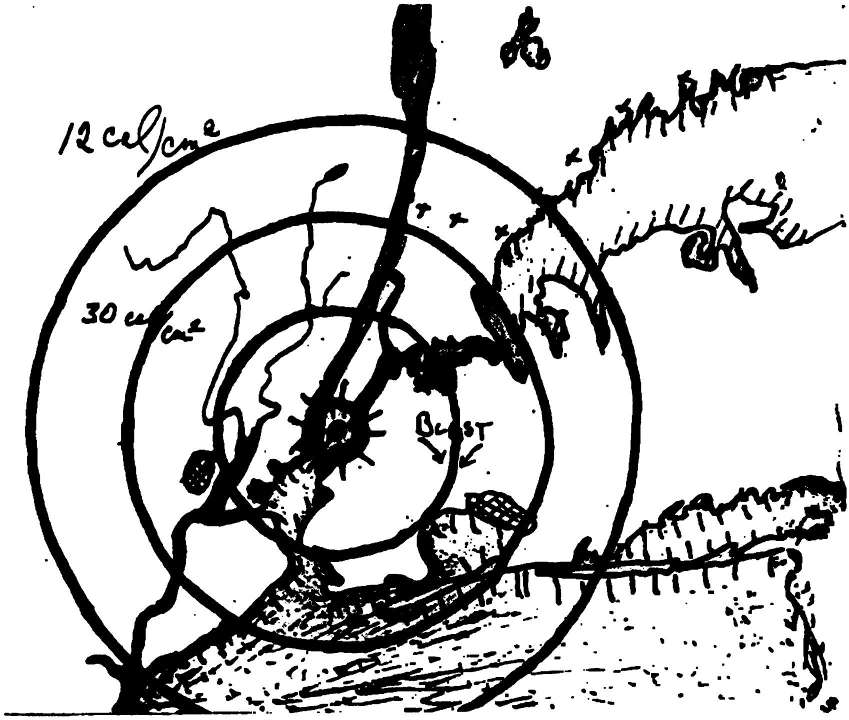
burns on the unprotected skin at the 12 cal./cm.² line, and those within the 30 cal./cm.² line would suffer severe burns from ignited clothing.

FIGURE III



The next line in toward the center is roughly the 7-pound-per-square-inch blast line which would result in demolition of brick construction buildings and pretty general structural damage within that radius. Of course, the small central section is the fireball itself and utter and complete destruction.

Senator ANDERSON. That would mean that if there was a direct hit of the size you have indicated on downtown New York, it would take out an area, as far as complete destruction is concerned, maybe 3 miles down toward the Battery and 3 miles on up if correctly placed, and everything within that area would be destroyed.

Dr. HAM. Yes, sir; I think that is correct.

Senator ANDERSON. Then there would be this other area which runs out to the end of the next circle which would take in all the nearby areas in New York and go up into Westchester County.

Dr. HAM. That is correct.

Dr. MIXTER. It would catch the lower tip of the Bronx here, it would miss the upper tip of Manhattan, pretty well demolish Brooklyn and a good piece of Queens, and raise cain in New Jersey. This is the destruction of brick-faced and steel buildings.

Dr. HAM. Dr. Mixter, being from New York City, is much better able to describe this than I.

Dr. MIXTER. This is 3 miles across town from point zero arbitrarily picked in lower Manhattan. Actually it is not 3 miles from ground zero up and down but 3 miles clear across.

Senator ANDERSON. Thank you very much. It helps sometimes if you are able to recall which spots are which when a map is not before you.

Dr. MIXTER. This outside line brings you out to about Glen Cove somewhere.

Dr. HAM. Passing on now to secondary burns from ignited materials and fire storms, experiments in the laboratory and in the field have collected an immense amount of data on the ignition characteristics of various materials, including most types of clothing, fabrics, plastics, wood, building materials, trees, and vegetation. Secondary fires would be started far beyond the 12 cal./cm.^{2} radius above referred to, but clothing would not ignite at these levels. Clothing modifies thermal injury by the following mechanisms:

1. Reflectance.
2. Slowing heat transfer.
3. Self-destruction.
4. Smoke.

Potential dangers from clothing are:

1. Catching fire.
2. Melting.
3. Fumes.

Laboratory and field experiences have shown that features desirable in clothing for the prevention of thermal injuries are:

1. Light color.
2. Looseness of fit.
3. Multiple layers.
4. Complete coverage.
5. Nonflammability.
6. Freedom from melt, toxic fumes, et cetera.

Some of the most extensive and destructive burns encountered in ordinary medical practice result from burning clothing. Such burns are usually deep and circumferential in extent. Obviously, dark materials with a low ignition temperature are hazardous during nuclear attack.

The importance of the blast wave which follows the thermal flash must not be overlooked. Blast destruction of electric lines, gas mains, petrol tanks, et cetera, may start local conflagrations in many areas. It is not known to what extent and in what proportions the thermal pulse and the blast wave contributed to the initiation of fires at Hiroshima; about 20 minutes after the detonation, the phenomenon known as fire storm developed. This consisted of a wind which blew toward the burning area of the city from all directions, reaching a maximum velocity of 30 to 40 miles per hour at about 2 hours after the explosion. Judging by descriptions from survivors at Hiroshima, this fire storm was responsible for a hideous number of casualties, most of which were severe burns.

The ignition hazard from the thermal radiation of a 10-megaton surface burst will extend over a circle about 25 miles in radius. At the outer edge of this circle, ignition will be mainly started in fine fuels (such as scattered newspapers, discarded cartons, trash piles,

et cetera) which can then spread to buildings. The actual hazard under any specific set of conditions is extremely difficult to assess, as it will vary with the temperature and moisture content of the flammable materials, the wind conditions, and the transmissibility of the atmosphere to the thermal radiation (which in turn depends on haze, cloud cover, humidity, et cetera).

A fire circle 25 miles in radius encompasses an area of over 1,900 square miles and, if the weapon detonates near the intended aiming point, will include the most densely populated sections of the target complex, which means that under certain clear atmospheric conditions, everyone and everything within this tremendous area would probably be subject to a grave thermal hazard and many consumed in the holocaust.

Representative HOLIFIELD. I can begin to see now why you thought that the cart was before the horse in a way, as far as radiation in this restricted area is concerned.

Dr. HAM. Yes, sir.

Representative HOLIFIELD. As a matter of fact, your fire storm in a city, in any large city, would be so great that it would cause the death of the people without waiting for radiation.

Dr. HAM. Yes, sir. This is the point we wanted to stress very strongly to the committee. While this is not the only consideration that one must think of this immediate environment of burning and think of the other hazards that we have been talking about in terms of trying to meet them within such a difficult environment.

Representative HOLIFIELD. In your computation of the outside air rushing into this funnel, or this rising mushroom, have you considered the deprivation of oxygen from people that might even be in ordinary basements?

Dr. HAM. Yes, sir. I am very glad you brought that problem up because I think in the eventuality that a fire storm does develop that this business of asphyxiation would have to be taken into consideration. Bomb shelters, for example, or people who had taken refuge in basements of their houses within this storm area might not only be incinerated at a later date but might be deprived of oxygen and become unconscious well before then. I think this experience has been explained in the U.S. strategic bomb survey during World War II and some of the experiences of survivors of fire storms at Hamburg and Tokyo. This deprivation of oxygen is a very real factor in a fire storm and a tremendous hazard itself.

Representative HOLIFIELD. This would only be effective in that area fairly close to the uprising column of fire and smoke. A few miles distant it would merely be in the form of a rushing wind that would come through the basements, would it not?

Dr. HAM. Sir, not necessarily so because I envisage under ordinary conditions that there would be conflagrations, let us say, in New York City out to that outside red line in the diagram that Dr. Mixter is pointing to. The fire storm might develop somewhere near the central portion of where the bomb hit, but as these winds began to be sucked into the center and up into the hot gases or chimney effect these winds would become of increasing intensity, the conflagration on the outside would be fanned, and it is quite conceivable that this fire storm might eventually involve the entire 25-mile radius of New York

City. I would not like to say that there is any assuredness that you might not be in the fire storm anywhere within that vicinity.

Representative HOLIFIELD. I was not here when that map was put up. How far from the zero center is the outside circle?

Dr. HAM. That is approximately 20 miles.

Representative HOLIFIELD. Twenty miles radius, in other words.

Dr. HAM. Twenty miles radius; yes sir.

Actually, sir, I think these kinds of calculations depend on so many factors. I do not think anybody would have enough knowledge to estimate whether that should be 20 or 25 miles. In our particular figure it is 25 miles.

Representative HOLIFIELD. How many megatons is this bomb?

Dr. HAM. This was postulated as a 10-megaton drop on New York City which was taken as a typical city in this study that the committee started.

Representative HOSMER. May I ask, Have you actually made a study of this oxygen deprivation effect in relation to the type, size, and shape of the fire that would occur after a detonation of this character?

Dr. HAM. No, sir; I have not.

Representative HOSMER. Are you just speaking from the hip, so to speak?

Dr. HAM. I am definitely speaking from the hip. I am speaking from imagination, really, sir.

Representative HOSMER. The areas involved, the type of construction at the center, the gap, for instance, from the harbor area, might all change the conditions so that you actually would not have that occur or you might have it occur in greater intensity, is that correct?

Dr. HAM. This is quite possible. I just want to call to the attention of the committee the hazard of fire storm. I do not have the knowledge or the facts to say that one would definitely develop. I do feel very strongly that this is a strong possibility and I want to call these hazards to your attention. I am not speaking from any factual knowledge in this case.

Representative HOLIFIELD. There was such a fire storm in the large city in Japan where they used the petroleum incendiary bombs?

Dr. HAM. Yes.

Representative HOLIFIELD. I cannot think of the city,

Dr. HAM. Tokyo?

Representative HOLIFIELD. And Yokohama was the city, because I visited it shortly after the war and saw for myself the damage. Hiroshima and Nagasaki had fire storms, also.

Dr. HAM. Nagasaki did not but Hiroshima did, sir. Nagasaki, because of its peculiar configuration, the valleys and so forth, did not develop a fire storm for reasons I don't believe are too well understood.

Senator HICKENLOOPER. Dr. Ham, I don't mean this to be a facetious question, but with this catastrophic situation you describe here, why make storm shelters or why take any precautions at all to ward this off?

In other words, it seems to me it is like the old saying, "If the devil doesn't get you, Fatimas must," with all respect to Fatimas. If you don't get killed in the blast you may get killed in the radiation. If you don't get killed in the radiation you get killed in the fire storm.

If you do not get killed by the fire you get killed by lack of oxygen in this area. I am asking you seriously what object is there particularly in putting tremendous effort into building shelters.

Dr. HAM. I do not know whether you were present when I started out. I said that I felt in a certain sense we might possibly have the cart before the horse. We would have to survive first and then see whether we could protect ourselves from the fallout. In given areas such as specified in this problem, assuming a direct hit, what you say, sir, is quite correct. Why do anything?

I am afraid this is something that I want the committee to envisage.

Senator HICKENLOOPER. I am not advocating doing nothing. I don't mean that. We cannot always anticipate that if a strike is made that the point of impact will be at X point on the map. It may be some place else. It seems to pose a lot of questions.

Dr. HAM. Yes, sir; I think it does. Of course, I think the accuracy of an enemy is something you always hope there will be a little leeway on, and it might well be that a target area designated for the Capital in Washington might land in Alexandria or in Richmond. One can't be sure of these things. Except under the actual conditions I think one is justified in taking what precautions they can. The rest of it is in the hands of the fates, so to speak.

Representative HOSMER. More or less like a safety belt in an automobile. It gives you a better chance.

Dr. HAM. Yes; I think that is correct, sir.

Representative HOLIFIELD. Could I ask you if the fire storm would start the local radiation return? Would there be any distortion to the pattern?

Dr. HAM. I don't feel, Mr. Holifield, that I am competent to answer that question. I could visualize to this extent: These tremendous winds and a chimney effect at a later time I would think might readily distort the pattern in this 25-mile radius we are thinking about. I have never seen any figures or any such calculation taken into account in regard to fallout. It would seem to me that this would be something that we should think about, sir.

Senator HICKENLOOPER. Would there be a vacuum effect in this phenomenon?

Dr. HAM. I don't think so, sir. I think it is more like being in a hurricane.

Senator HICKENLOOPER. Characteristic of these bursts, or one characteristic, is a push out and then a push back; is there not?

Dr. HAM. Yes. But this is the blast wave. The fire storm which we were discussing is a later phenomenon long after the blast wave is gone. This is, in general, winds coming around the entire periphery from the outside in and going up through the hot chimney of the burning central portion of the city. This is after the fireball and the mushroom are well up in the air.

As it occurred in Hiroshima 20 minutes after the bomb hit, the fire storm began to develop and reached a maximum intensity in roughly 2 hours and extended from 2 to 6 hours. So the blast wave is gone. I don't think there is a vacuum effect here necessarily.

Senator HICKENLOOPER. I was wondering if there might be a vacuum effect which would have a substantial effect on body tissues and life itself. If there is a sudden vacuum created as a result of this explosion, that is what I have in mind.

Dr. HAM. I don't know, sir. I think this is something that involves the blast effect which Dr. White is going to testify to and I prefer to leave that to him. I am here in the unfortunate role of being an apostle of fire and I think I had better stick to that, sir.

Representative HOLIFIELD. You may proceed.

Dr. HAM. When one compares this factor with the lethal fallout area resulting from the same surface detonation, one is immediately impressed by the fact that fire, in many cases, will impose a much greater hazard to many more people and buildings than the fallout. If one envisions a city complex of appproximately 25 miles in radius, in which the enemy is successful in detonating a 10-megaton surface burst near its center, then the entire complex will be at risk from fire, while only about 20 or 25 percent will be inside the lethal fallout area, most of which will be disposed downwind outside the highly populated area. The complete blast destruction zone is considerably smaller than either of the other two areas, being a circle about 7 miles in radius, or about 150 square miles.

Actually that area which Dr. Mixter has outlined is about one-sixth of the total area of 2,000 square miles encompassed by the outside red circle.

It is believed that fire storms are an almost inevitable consequence of a megaton drop on a large American city. Just what measures can be adopted for survival during a fire storm are not readily apparent. Survivors of the initial effects of blast, thermal and ionizing radiation from a megaton burst must cope also with the incinerating heat of fire storms. Severe burn casualties from secondary fires will outnumber vastly flash burn casualties from the fireball.

Thermal injury to the eye: The hazards of flash blindness and retinal burns from nuclear explosions have received increasing attention during the past few years because of the extremely long distances over which these phenomena have been produced. Neither flash blindness nor retinal damage constitute major hazards during the daytime because of the restricted pupillary diameter which limits the amount of light entering the eye; furthermore, the blink reflex, 100–150 milliseconds, protects the eye from undue amounts of radiation, except in those cases where the thermal pulse is delivered within extremely short times. This is the case for low-yield weapons on the ground and for weapons of any yield exploded at very high altitudes. Under the conditions stipulated in this investigation, the hazards of flash blindness and retinal damage would be negligible.

Representative HOLIFIELD. On that point, let me ask you, what happened in the case of the eyes of the animals that were exposed to the Johnston Island test? Can you testify on that?

Dr. HAM. Sir, with your permission I would like to defer that until we have completed the paper and then Col. John Pickering is in the audience here and has some slides and, if you would permit me, I would very much like to call Colonel Pickering to give some testimony

on that effect. He conducted these experiments and would be the best person to talk to you about them, sir.

Representative HOLIFIELD. That is fine. You may proceed.

Dr. HAM. Flash blindness is a reversible photochemical effect in which the visual purple substance is temporarily depleted, resulting in loss of vision which may persist for several seconds or even minutes. It presents an operational hazard for military personnel at nighttime, especially jet pilots who cannot afford loss of vision even for a matter of seconds. Flash blindness does not represent a major hazard for personnel on the ground during daylight hours.

Representative HOLIFIELD. This seems to go contrary to some of the things which many of us believed. Many of us have attended these tests in Nevada and some of us in the Pacific. Even though we were as far away as 9 or 11 miles from the point of detonation we have always had to wear very heavy dark goggles, so heavy that you could look directly in the sun and it looked just like an orange.

We were told to keep that on until the fireball vanished. While you have brought out in your previous paragraph that the blink reflection is 100–150 milliseconds, isn't it true that an ordinary curiosity of people to glance at the light would cause them to open their eyes and gaze at the fireball during the seconds it was in existence and thereby injure their eyes? We were cautioned in all of the tests from the small ones up to the megatons test itself not to do this.

Dr. HAM. This is very true. The difference here is that you are expecting this blast and if you looked at the blast deliberately without those heavy glasses given one in Nevada or in the Pacific I think undoubtedly you could suffer a retinal burn and flash blindness perhaps. For a population on the ground which was subjected to a megaton burst such as we are talking about here, if the person through curiosity did deliberately look at this burst I don't think anyone could say that they would not receive a retinal burn.

Therefore, as I have tried to outline a little bit further on in here, I think both military and civilian personnel should be instructed by all means never to look at the flash. To please try not to be curious. I don't think anyone could say if you tried deliberately to look at the fireball you would not get this.

Representative HOLIFIELD. This sort of thing has not been told to the American people.

Dr. HAM. It should be, sir.

Representative HOLIFIELD. I understand it should be. We have here a population of 175 million people and as far as I know there has been very little publicity given to this particular factor. I would think that where there is a group of as many as 260 weapons being detonated it would be logical that a substantial portion of the people that were up and about during the daytime hours would be attracted to a flash of light and naturally glance toward it. If they did this, if this natural inclination were followed, they might shut their eyes again if it were bright enough to be painful. But if it were not and they continued to gaze for several seconds wouldn't there be a situation of temporary blindness?

Dr. HAM. Yes, there definitely would. Possibly we could not definitely exclude permanent damage of retinal burns if they did this. I think they should be instructed along these lines in civil defense. My only reason for saying that the flash blindness and retinal burn hazard is negligible compared to the other things that I am trying to visualize is an extremely arduous situation in which people are running hither and thither trying to escape the glass and flying debris and with their clothes on fire and suffering from the intense pain of flash burns; certainly having flash blindness at this time, as Dr. Tompkins and I were talking about a little while ago, would add to the hysteria and confusion of the victim; and then not being able to see, either; this would definitely add to the whole effect.

Representative HOLIFIELD. Could I pursue the subject a little further and ask if those outside of the 20- or 25-mile radius would be safe from injury? Say 30 miles or 35 miles where they would not actually have the fire hazard or even lethal blast damage but where they might still be easily within visual range of the fireball.

Dr. HAM. I think that is a very good point, sir. I think probably we can call on a normal experience that we all have. On a bright day if you try to look at the sun you know that one suffers momentary flash blindness. I think anybody at any radius up to the curvature of the earth who looked at the fireball of a megaton burst deliberately would probably undergo some degree of flash blindness. Conceivably one could also get a retinal burn though I think this is less probable in daylight hours because of the very restricted pupil and so forth.

I would not rule it out. It is so difficult to assess these situations in their entirety.

Representative HOLIFIELD. Would this same thing be true of antimissile missiles used against incoming aircraft or would they be far enough away?

Dr. HAM. No, sir. I must say I think it would be true there, too. Perhaps the curiosity factor would be even more intense in this case. I do not think flash blindness or retinal burns could be ruled out completely there, either.

Senator HICKENLOOPER. Dr. Ham, how long after the incident of the flash will one be apt to suffer flash blindness or retinal damage? In other words, I understand if you happen to be looking right at the point of the flash at the time of the flash, that can occur. But suppose you look at it, 2 seconds after the flash has occurred, will you still suffer retinal damage and flash blindness?

I presume you have to take into consideration how far away you are from the burst. How long does that intensity of effect occur? Is it seconds or microfractions of seconds, or just what is it?

Dr. HAM. For a 1-megaton burst, the fireball would be of an intensity for roughly 15 seconds, where if one looked at it you would perhaps get flash blindness and conceivably one could get retinal damage. A 10-megaton burst would cause a fireball that would be very brilliant and might produce flash blindness for approximately 40 seconds.

In trying to answer the other part of your question, flash blindness is a momentary and a reversible biologic effect in the sense that you have this depletion of the vision for a limited amount of time. It

comes, back usually in a matter of seconds; always, I believe, in a matter of minutes. You would again have your sight. Retinal burns, if you are unfortunate enough to suffer them, do not come back. This is what we call irreversible biologic damage and you now have a hole burned in your retina. This may or may not be serious depending on whether it hits the area where we have central vision or whether it hits somewhere in the periphery of the retina. If it hits in the periphery of the retina this need not be a serious lesion so that it would not incapacitate a man very much.

Senator HICKENLOOPER. Retinal burns depend on the distance which one may be from the point of flash?

Dr. HAM. Yes; definitely.

Senator HICKENLOOPER. Flash blindness would also depend upon the distance to a considerable extent?

Dr. HAM. Yes.

Senator HICKENLOOPER. The farther away you are the less the hazard?

Dr. HAM. Yes, sir.

Senator HICKENLOOPER. It is like looking at a dimmer light.

Dr. HAM. That is correct, as I understand it.

Senator HICKENLOOPER. We suffer flash blindness around here in committees very often, especially the more interesting hearings. I am just wondering if someone were in a house 20 miles away from the point of burst, the burst was heard and this person rushed out of the house to see what had gone on, I presume the intensity and size of the burst, the intensity of the light and so on, would have an effect. But that period of time that it would take people to rush out into the streets or rush around to the windows to look at the fireball or the flash would have a tendency to greatly lessen the degree of permanent injury. Would that not be the case?

Dr. HAM. That is correct, sir.

Senator HICKENLOOPER. So the very serious injuries in great percentage would be more apt to occur to someone who happened to be in the open and who happened to be looking in the general direction of this burst at the time it occurred.

Dr. HAM. That is very definitely true, sir, in my opinion.

Another factor is that if a person is out in the open on a brilliant sunlight day his pupils are restricted to perhaps 1½ or 2 millimeters If he comes from a house inside in the daytime his eye might be accommodating about 4 millimeters, so as you rushed out from the dim interior of the house to the very brilliant exterior which might be 20 tmes brighter than sunlight, the effect of flash blindness and retinal burns would be magnified in this case. It is a point that if people take cover with initial warning, even if they have just enough warning to get indoors we can do away with the hazards of flash blindness and retinal burns if they can be trained not to use their curiosity and look at the fireball.

Senator HICKENLOOPER. Doctor, is it not true that the instinct is not to look at such things because of the painful results?

Dr. HAM. I do not think so, sir. Many people have suffered retinal burns without knowing it. This is not necessarily a painful exposure. Flash blindness carries a certain amount of psychological difficulty

and discomfort with it, but the retinal burn is not necessarily a painful thing in itself.

Representative HOSMER. I am trying to distinguish between the person who happens to be looking in the direction at the time that the blast occurs without warning, and the one who perhaps has faced the other direction. Would he be unlikely to turn around in the face of a very brilliant flash of light? You see people often when a flash bulb goes off, their hands go up to keep the light away. I thought there would be some instinctive action there that would afford a measure of protection.

Dr. HAM. I don't think I have any factual evidence. I can only think of my own personal experience in looking at some weapons which I have witnessed. I think most of us have had the common ordinary experience of sometimes looking at the sun. I think nature seems to take care of you if you look deliberately at the sun. It is pretty hard to get a retinal burn. You can get a mild degree of flash blindness. Almost instinctively it makes your eyes water, and you blink at 150 milliseconds. You can open your eyes again but every time you do so your tears flow. It is very difficult to look at the sun for any length of time. I think nature protects you from this under ordinary conditions. I do not know what a person would do in the case of the fireball except that the hazard would be greater than looking at the sun. This is for certain.

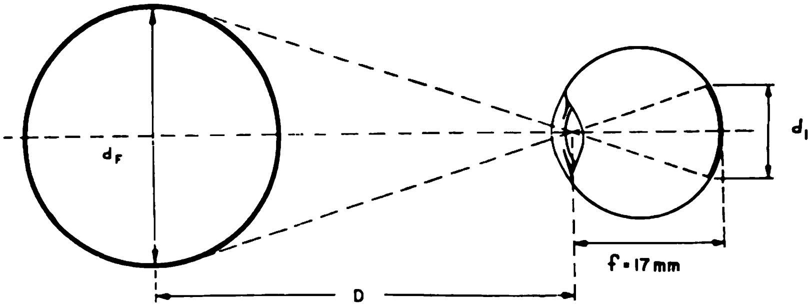
Shall I go on, sir?

Representative HOLIFIELD. Please proceed.

Dr. HAM. The optical system of the eye is designed to reproduce a faithful image of a bright object on the retina. As the distance from the fireball increases the thermal energy incident on the cornea decreases as the square of the distance but the image diameter of the fireball on the retina also decreases in exactly the same proportion.

The big circle to the left is supposed to illustrate the fireball which in reality would be much further out and a very small angle coming into the eye through the lens and then back to the retina. You see that the two angles there by the fireball at the eye are equal. This means, therefore, that the ratio of the diameter of the image on the retina to the diameter of the fireball is inversely proportional to the distances of the two. The fireball may be several miles, 20, 30 miles or whatever distance you took and the distance between the lens effect of the eye, the focal points to the retina, is about 17 millimeters, which is roughly a fixed quantity. This means that for any given size of fireball you get a corresponding size image on the retina reproduced rather faithfully. Neglecting attenuation by the atmosphere, the result is that the thermal exposure on the retina remains constant, regardless of distance from the fireball. Figure IV depicts in schematic fashion the basic optics of this phenomenon. It is possible, therefore, to produce burns on the retina out to distances which greatly exceed any of the other prompt effects of nuclear explosions. Both civilian and military personnel must be instructed not to look at the fireball during the radiative phase.

FIGURE IV



$$d_I = d_F \frac{17}{D}$$

Representative HOLIFIELD. You have used the term "greatly exceed." Do you have any experimental knowledge which enables you to put that into specific focus?

Dr. HAM. I do have some, sir. I think Colonel Pickering will speak about this again, too.

Representative HOLIFIELD. That is fine.

Dr. HAM. If we could defer that, I would prefer it.

Representative HOLIFIELD. Go right ahead.

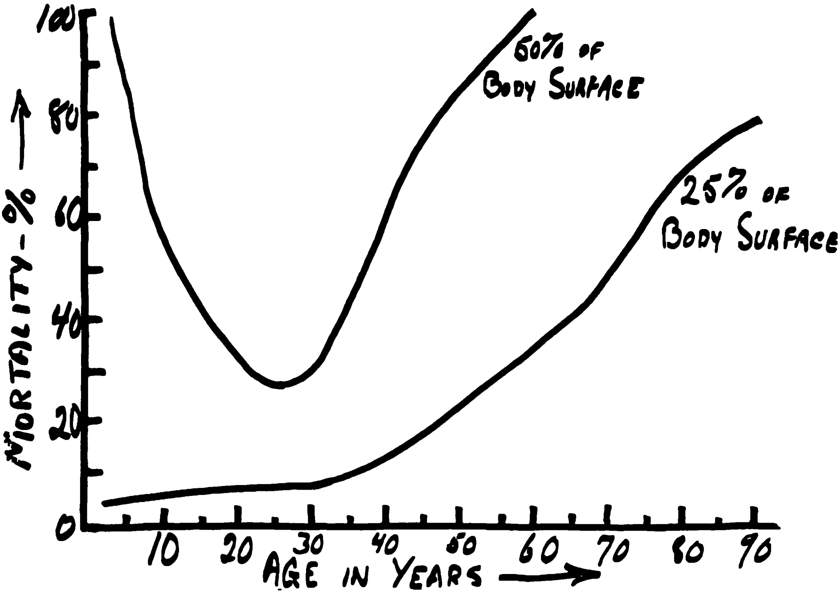
Dr. HAM. Retinal burns from viewing the sun during an eclipse are well known to ophthalmologists. The fireball of a nuclear weapon is many times brighter than the sun and will produce severe retinal damage if viewed deliberately.

BURN TREATMENT

Nuclear warfare on the scale being discussed here would produce severe burn casualties out of all proportion to any previous medical experience.

Figure V illustrates the mortality to be expected from burns as a function of burn area and age of patient. These mortality figures apply only to people who receive optimum care in a hospital burn clinic where complete resources of medical science are devoted to the burn patient.

FIGURE V



Representative HOLIFIELD. Of course those facilities would not exist under these conditions.

Dr. HAM. These facilities would be absent, yes, sir.

A burn covering 25 percent of the whole body would cause death to less than 10 percent of the patients in the age group 20–35 years; for older patients the mortality increases rapidly. For burns of 50 percent total body area or more the chance of survival decreases rapidly for all age groups.

It is, you will notice, at a minimum around 25 years of age, which indicates the young person's resistance or better chance of survival to severe trauma.

It has been estimated that following a nuclear weapons burst, there will be approximately 1 doctor to every 500 survivors, most of whom will be casualties themselves.

Representatives HOLIFIELD. Is there 1 doctor today for every 500 people in the United States?

Dr. HAM. I do not have that figure. I will ask Dr. Mixter to speak on that score for a moment, since he is an M.D. We were trying to estimate last night, and did not have the data with us, just how many doctors there are in the United States.

(Supplementary information furnished by Dr. Ham follows:)

[For release at 2 p.m. (e.d.t.), Monday, June 15, 1959]

DEPARTMENT OF DEFENSE,
OFFICE OF PUBLIC AFFAIRS,
Washington, D.C.

JOINT AEC–DOD STATEMENT OF RESULTS OF THE TEAK AND ORANGE SHOTS IN THE 1958 HARDTACK SERIES

During the Hardtack nuclear weapons test series in 1958, Joint Task Force 7 (composed of personnel from the Department of Defense, Atomic Energy Commission and their contractors), conducted a weapons effects program to obtain information on the effects of nuclear detonations at high altitudes. The program was carried out in coordination with the Atomic Energy Commission.

To achieve the objectives of the program, two high altitude shots were fired in the vicinity of Johnston Island, approximately 700 miles southwest of Honolulu, Hawaii. The first shot named Teak was detonated on July 31, 1958, at 11:50 p.m., Johnston Island time, at an altitude in excess of 200,000 feet; the second shot named Orange was detonated at an altitude of about 100,000 feet on August 11, 1958, at 11:30 p.m. The nuclear devices were carried aloft by missiles, and were the first megaton devices ever detonated in the stratosphere by the United States.

As on all Department of Defense weapons effects shots, a number of measurements were made including those of blast, thermal radiation, and electromagnetic effects. Some of the results obtained from the Teak and Orange shots are discussed in the following paragraphs.

AURORA AND VISIBLE EFFECTS

With respect to visible effects, Teak and Orange were by far the most spectacular shots ever fired by the United States. Teak produced a bright fireball which grew rapidly and immediately started to rise at a rate of approximately ½ to 1 mile per second. An aurora developed from the bottom of the fireball and spread rapidly to the north. The fireball reached a diameter of approximately 11 miles in 0.3 second and a diameter of better than 18 miles in 3.5 seconds. The fireball glowed brightly for about 5 minutes. The fireball of the Orange shot developed much more slowly, and the aurora, which was somewhat less pronounced than Teak did not appear until the fireball had risen.

THERMAL RADIATION EFFECTS

The intensity of thermal radiation (heat) from the Teak explosion, measured on the earth's surface at Johnston Island, was insufficient to produce first degree (least serious) burns in human beings.

For the Orange shot, no thermal radiation measurements were obtained due to cloud cover that existed at detonation time.

The program to measure thermal radiation from the Teak and Orange shots included a biomedical project using rabbits to investigate the hazard of burns to the retinal tissues of the eye.

For many years the clinical phenomenon of retinal damage caused by the radiant energy of the sun has been known and numerous cases have been documented. Most of these cases have occurred while watching solar eclipses without eye protection; thus, this type of retinal lesion has become known as eclipse blindness. Since the fireball of a nuclear detonation attains internal temperatures comparable to that of the sun, the predicted thermal energy release is of sufficient magnitude to cause concern about retinal damage in human beings who view nuclear detonations without proper protection. In order to receive permanent serious impairment of vision from a high-altitude burst, an individual would have to be looking directly at the nuclear detonation at the time of burst.

From previous tests at the Nevada test site and the Eniwetok proving ground, the thresholds for retinal damage has been generally established for detonations at or near the earth's surface.

The primary objective of the Teak and Orange biomedical project was to determine the extent of retinal damage caused by exposure to a high-altitude,

high-yield nuclear detonation. Rabbits were placed at distances up to 300 nautical miles from the point of detonation in order to obtain the necessary data.

The biomedical project showed that a very high altitude nuclear explosion can be particularly damaging to the eye because of the rapid rate at which the power pulse delivers thermal energy and the relatively low atmosphere attenuation encountered. A high-altitude detonation in the megaton yield range, such as Teak, delivers a great percentage of its thermal energy during a small fraction of a second after the detonation. Consequently, with a blink-reflex time of just over a quarter of a second for the rabbit and less than a quarter of a second for man, nearly all of the radiant exposure from a very high-altitude burst is received by the retina before the eye can be protected by blinking if the person is looking directly at the burst at the time of detonation. This is in contrast to low altitude detonations of the same size, where the power pulse is much slower in overall delivery of its thermal component and where the blink reflex can provide a measure of protection.

Small retinal burns were produced in the rabbits at distances up to 300 nautical miles. Burn diameters consistently correlated with distance from the burst, with progressively smaller lesions being encountered at increased distances. For example, the burn lesions were approximately 2 millimeters in diameter at about 40 miles distance, decreasing to 0.5 millimeter at 300 miles. Corresponding lesions of smaller diameter might be expected at larger distances provided the burst height were great enough to allow a direct view of the fireball over the edge of the horizon. Curvature of the earth will cause the position of the fireball to be below the horizon, and therefore incapable of inflicting retinal damage.

In order to preclude damage to the sooty tern, a large bird indigenous to the Johnston Islands, special precautions were taken during the Orange shot. A water spray simulated rain and kept the birds grounded. Smoke together with local clouds further attenuated thermal effects.

No precautions were necessary for the Teak shot due to its higher altitude. The protective measures for the Orange shot were successful.

SUMMARY OF TEST OBJECTIVES AND RESULTS REGARDING FLASH BLINDNESS AND RETINAL BURNS

The effect of nuclear detonations on human eyes was recognized early in the testing procedures when the Aviation School of Medicine of the U.S. Air Force performed Project 4.3, "Flash Blindness," in Operation Buster. The objective of this project was to evaluate the visual handicap which might be expected in military personnel exposed, during daylight operations, to the flash of an atomic detonation and to evaluate devices developed for the purpose of protecting the eyes against visual impairment resulting from excessive exposure to light. The data obtained on this test, as revealed in the test report, showed that no serious handicap is encountered during exposure to atomic detonation during daylight operations at the distance from the detonation which would be safe from the standpoint of other hazards. This conclusion was subsequently disproved by the recent Hardtack test series in the Pacific, using rabbits as specimens.

In the Tumbler-Snapper test series retinal burns were not investigated, with the Air Force School of Aviation Medicine this time investigating flash blindness. However, on this series some work was done on atmospheric transmissivity, which has proved subsequently to be of some help in the problem of retinal burn prediction.

In Operation Upshot-Knothole, research was conducted to determine to what degree the flash of an atomic detonation impairs the vision and reduces the efficiency of military personnel during nighttime operations. This is a serious problem because the individual has pupils which are more or less widely dilated, depending upon the amount of light to which the eye is being exposed prior to detonation. The conclusion was that a significant loss of central peripheral vision occurs temporarily following exposure to an atomic detonation. It was also concluded that the types of filters tested served to shorten by about 30 percent the normally long period of incapacitation in unprotected individuals as measured in the previous Tumbler-Snapper operations.

The objective of the retinal burns portion of this test was to find the extent of damage caused by exposure of the dark-adapted rabbit eye to the high intensity illumination of an atomic detonation. with appropriate evaluation to determine whether human eyes might suffer similar injuries under the same

exposure conditions. The conclusions from this investigation of retinal burns are that the potential danger to the retina is far beyond previously estimated distances, and in exceptionally clear air the nominal atomic bomb (20 kilotons) can be expected to produce atomic retinal lesions in humans up to 36 miles in the daytime and up to 40 miles at night. These conclusions were based upon the results obtained in the experimental exposure of 700 pigmented rabbits to the atomic flash.

Again, in Operation Redwing, investigation of retinal burns was effected as a sequel to Operation Upshot-Knothole. The significant conclusion of this test was that retinal burns were produced at distances greatly exceeding the limits for any other prompt and significant biologic effect of nuclear detonations. It was recognized that the problem of this type of burn was one of increasing significance at higher altitudes where lack of atmospheric attenuation increases not only radiant exposure but also the rate at which radiant energy is delivered and the distance to which a given amount can be transmitted.

As a result of the previous findings, it was the objective of the retinal burn project in Operation Hardtack to determine to what extent retinal burns may be produced for detonations at very high altitudes. It was a conclusion from this study that minimal retinal burns can be produced on the ground surface at distances closely approaching 300 nautical miles from relative ground zero from a megaton detonation at excess of 200,000 feet altitude. For a megaton range at one-half of this altitude, the critical surface distance for the production of minimal-type lesions more nearly approaches 225 nautical miles. It was pointed out that these distances would be increased if the altitude of the observer were also to be increased.

STATEMENT OF DR. GEORGE MIXTER, JR., ASSOCIATE PROFESSOR OF SURGERY, NEW YORK UNIVERSITY SCHOOL OF MEDICINE

Dr. MIXTER. If I may interject for a moment, the number of doctors in the United States divided into the population is not precisely what we need because we have to know the ratio of doctors to potential patients in the area that is actually involved.

Representative HOLIFIELD. I understand that. If we don't start out with a doctor for every 500 people and we know that doctors are concentrated in the populated areas, and this is the area that is attacked, it would seem that unless you can show some real reasons for your statement you might be in error.

Dr. MIXTER. In the suburban areas, in one target area, for example the one we showed, it is approximately 1 to 500. This would be widely different in different areas.

As you know, the doctors tend to have their offices in the center of town and many of them live there. In certain smaller cities this would result in wiping out almost the entire medical profession. On the other hand, in other cities where the suburbs are building up rapidly there would be a very high percentage. We picked the number 500 not as indicating that there would be precisely 500 but perhaps somewhere within a hundred or a thousand.

Representative HOSMER. It doesn't make much difference what the ratio of doctors to patients is if they are casualties.

Dr. MIXTER. That is right. I find it difficult to handle 30 patients in 2 hours. Under the conditions of this present exercise, there are not enough doctors living to cover the small area that is concerned. It is out of all credibility.

Representative HOLIFIELD. I think we ought to be very realistic in making these assumptions and not mislead the American people by saying that there will be normal facilities or normal ratios of doctors under conditions like this.

Dr. MIXTER. The exact number is presumably incalculable. In any case the number is mentioned only as an indication of the complete hopelessness of the problem confronting the medical profession.

(The following was subsequently handed to the chairman of the subcommittee:)

DEAR MR. HOLIFIELD: There are 226,625 physicians in the United States, of which 16,598 are in Government service, that is, Army, Navy, Air Force, Public Health Service, Veterans' Administration, and Indian Service. Figures are for the year 1958.

FRANK BARTON,
Secretary of the Council on National Defense,
American Medical Association.

Representative HOLIFIELD. Proceed, Dr. Ham.

Dr. HAM. Yes, sir. It is obvious that under such conditions it would be impossible to give burns or any other casualties such treatment as is now known to result in minimal mortality. The surviving doctors' primary responsibility must be to select those casualties reasonably capable of ultimate survival, and to concentrate every effort upon their survival. This means that under conditions of inadequate supplies of opiates, dressings, and sterile fluids, the vast majority of casualties will receive only token treatment. It is not the province of the present discussion to define accurately either the number of casualties or how they will be treated, but it must be unequivocally stated that, under the conditions predicated for this investigation, only a small percentage of the injured population could, or indeed should receive even an approximation to adequate medical treatment.

Burn victims might be sorted into three groups according to percentage burn area, 25 percent or less, 25 to 50 percent, and greater than 50 percent. Those having burns covering 50 percent of the body area or more would be given opiates for pain and neglected; the group having 25 to 50 percent area burns would be treated with all available resources in the field; the 25 percent or less groups would be given oral electrolyte treatment, opiates for pain, and dismissed.

Representative HOLIFIELD. Would you please tell me what oral electrolyte treatment is?

Dr. HAM. Dr. Mixter will.

Dr. MIXTER. This very simply means salt water mixed in a proportion which will not make the person ill but will supply them with the salt, and if you have the soda bicarb, which is the ideal fluid, to allow their life to be prolonged. Extensively burned people are not capable of eating any solid food. They won't accept it. Various emergency fluids have been worked out. This information should be a part of the information of any one concerned with any type of disaster work. It should be known because the fluids used for intravenous use will be in short supply, indeed if there are any. Even pure water suitable for drinking will be in short supply. Oral electrolyte is salt water.

Representative HOLIFIELD. That is very plain. Even I understand that.

Dr. HAM. Burns involving more than 25 percent of the total body area represent severe traumatic cases demanding at least five details of emergency treatment: (1) relief of pain; (2) emergency dressing, if possible; (3) prevention and treatment of burn shock; (4) salt and

water requirements to insure adequate urinary output; (5) the most feasible antibiotic therapy to aid in combating infection. Of all the types of traumatic injury following a nuclear attack, severe burns make perhaps the greatest demands upon medical personnel and resources. Successful treatment requires stockpiles of plasma, whole blood, plasma substitutes, antibiotics, emergency dressings, narcotics, et cetera. The treatment period is long and arduous. Burn wounds greater than first degree always become infected and prolong the treatment phase. Exposure to ionizing radiation complicates the picture because the body's defenses against infection and bleeding have been impaired. Combined injury from thermal and ionizing radiation presents grave problems in therapy.

The conclusion seems inevitable that millions of severe burn casualties would overwhelm our capacity for adequate medical treatment. Mortality figures for burn victims would be extremely high. It is no exaggeration to say that, after nuclear attack, burn casualties represent the most serious immediate medical problems facing the Nation.

Representative HOLIFIELD. Thank you very much, Dr. Ham.

Are there any questions of the witness?

Representative WESTLAND. Mr. Chairman.

REPRESENTATIVE HOLIFIELD. Mr. Westland.

Representative WESTLAND. The nations have been using fire as a weapon for hundreds of years, all the way from the Indians using bow and arrows with fire on them to set the house on fire, up to recent wars with flamethrowers, napalm bombs, and so forth. Isn't what you are really saying here is that man has now created a weapon with which he can destroy his fellow man in greater quantities and with greater efficiency? Is that not just about the size of it?

Dr. HAM. Yes, sir; I think that is, with very great efficiency, especially in terms of magnitude of something that we have never had previous experience in. In modern warfare in the past there have been filled hospitals and bad burns have been able to be treated because they came in in small numbers. But you are here faced with the instant production, so to speak, of perhaps millions of burns casualties, and the question is what can we do about it. The answer we are trying to drive across is that the ordinary treatments that we do adopt under the best conditions for burns would be absent and that the mortaility figures for burns would be much greater under such conditions. It is our estimate and feeling that burns would produce a tremendous amount of mortality in the country under nuclear attack.

Representative WESTLAND. You are saying that the medical protection would simply be unable to cope with such a situation.

Dr. HAM. Exactly, sir.

Representative WESTLAND. I would assume that this same information which you have presented here so well this afternoon is available to other nations, too, who possess this lethal weapon.

Dr. HAM. Yes, sir; I think that is correct.

Representative BATES. Doctor, could not a lot of these things which you have suggested here be done by first aid treatment by people who have had a little experience in this field?

Dr. HAM. Yes, I think that is very true. I think Dr. Mixter would prefer to speak to you about that, Mr. Bates.

Dr. MIXTER. There is no question but that this would have to be the case. During the war, as many of you know, much of the important medical care given to the wounded was done long before anybody with an M.D. saw the man. Dr. Ham and I were both in the Marine Corps and we know this very well. The actual early treatment is going to be accomplished by lay persons who are not only well versed in how to do it but who possess the type of iron will which is not going to be overwhelmed by such catastrophies as this. This won't amount to more than 10 percent of the population. The other 90 percent are going to be running around like chickens with their heads cut off. We don't know who these people are going to be that will come to the fore. This means that for educational purposes the entire population must be versed in such field first aid procedures as will be necessary. It is impossible for any one to conceive, I am sure of the psychological impact of such a holocaust as we have been describing. We are going to have to rely on stable personalities who just happen to be at that place at that time and who furthermore have some knowledge of the proper first aid procedures.

Representative HOLIFIELD. Of course stability of action on the part of people comes about as a result of knowledge and training. Where knowledge is not imparted to them or information is not imparted to them and they have not been trained you cannot expect stability of action in the case of emergency.

Dr. MIXTER. You certainly cannot.

Representative HOLIFIELD. This is the condition that we are in in the United States today.

Dr. MIXTER. At the present time.

Representative HOLIFIELD. I am talking about today.

Dr. MIXTER. If I may cite the difference between the well trained and prepared group, I think the Coconut Grove is a fine example. I happened to be one of the interns at Massachusetts General the night that happened. We happened to have been trained as a civilian defense unit. We had what we needed. We had organization, Dr. Churchill took over. There was never any confusion and things were taken care of. Our patient load was for our size neither heavier nor lighter than in another hospital where an entirely different situation obtained for a considerable length of time. It was remarkable what that degree of training did for us.

Representative HOLIFIELD. It is no secret that our emergency supplies of all types of medicines, plasma, and so forth, are inadequate to begin with. Such amounts as we have are stored in flammable buildings and, in most instances, within the circle of the probable target area in the United States. I have supported, and I know my colleagues have supported, many millions of dollars for the purchase of these supplies. Yet without any exception that I know of, they are stored above ground in vulnerable buildings. Therefore the people of the United States cannot expect to have these supplies in case of emergency.

Dr. MIXTER. That is right, sir. There are two other problems that arise with storage of these vital supplies. One is the staggering cost to begin with. But we won't go into that. The second one is deterioration, which means that they have to be replaced at intervals. The

third one is pilferage. Where drugs are concerned, there is going to be pilferage as we all know, who have been in the Government.

Representative HOLIFIELD. That is right, under the present circumstances I agree with you.

Dr. MIXTER. Yes, sir.

Representative HOLIFIELD. Unless a system was devised whereby you rotated in normal use these materials from the emergency supplies and kept replenishing them. The job of preventing obsolescence in biotics and other types of supplies is almost impossible to comprehend.

Dr. MIXTER. That is correct. The problem is going to be to help those persons who survive, for whom there is some prospect of a future, and if this country were confronted, picking a number out of my head, with 20 million severe burns, it would be impossible to conceive of covering those areas of hospitalizing them. This could not be done. One's efforts have to be extended in the direction of promoting survival among those in whom it means something.

Representative HOLIFIELD. The whole problem, in order to be manageable, comes back to the necessity for doing the preventive work ahead of time and putting this into a manageable focus ahead of time. You can't catch it after it happens.

Dr. MIXTER. No, sir.

Representative HOLIFIELD. If you have not solved the key problems before hand of first sheltering as many people as possible, and second, protecting the supplies that they are going to need, then you have an impossible job. It may be very difficult even at best.

Dr. MIXTER. It will be difficult at best.

Representative BATES. Doctor, do you have a practical plan that can be implemented to accomplish this goal?

Dr. MIXTER. I, sir, am a surgeon and not connected with any of the agencies involved in such planning, although like anyone else in my profession once the leadership is established and a reasonable plan appears to be in the offing you only have to ask once.

Representative BATES. Do you believe a practical plan can be implemented?

Dr. MIXTER. Until I was called upon to help Dr. Ham with some of the aspects of the testimony, I had personally never visualized anything of the magnitude of what we are considering, and all I can say at the present time is that I am profoundly disturbed. I am sure that the problems of planning, even for such a degree of damage as this, will tax a good deal more than my brain to come up with something useful.

Representative BATES. Doctor, have you had a chance while you have been working on this at all to examine the plans of civil defense?

Dr. MIXTER. Not in sufficient detail to feel that I myself could pass on them reasonably.

Representative HOLIFIELD. I thought it would be good for the record at this point to state that I have met with the National Defense Committee of the American Medical Association on two different occasions during their conventions where this subject has been explored in great length. I can say that it is a matter of great concern to these people. They have appeared before congressional committees and have testified along this very point.

Dr. MIXTER. Yes, sir. I don't believe, however, that the medical profession has ever been confronted with catastrophe of the magnitude that we are discussing today. In our minds, those of us who have not had access to classified information, this is absolutely beyond comprehension.

Representative HOLIFIELD. Of course, we are not using classified information at all in these hearings. One of the reasons we are holding these hearings is to bring out the unclassified information, which is actually all that is necessary in this field, to start working on it.

Dr. MIXTER. All that we have to say is in the capabilities of "The Effects of Nuclear Weapons," and this is available to anyone at the Government Printing Office.

Representative BATES. Doctor, if we examine all the possibilities in chemical warfare and bacteriological warfare in addition to this, you really have a problem. This is only one tremendously important phase of an overall very, very dangerous potential situation.

Dr. MIXTER. Precisely.

Dr. HAM. Mr. Chairman, I wanted to say, sir, that the Office of the Surgeon General of the U.S. Army, Research and Development Board, under the leadership of Col. William S. Stone and later under Col. John Wood, and with the help of my old boss Dr. Everett Idris Evans, and many, many other people have considered this varying problem of mass burn casualties for many years. They operated on the thesis originally that we were talking about atomic bombs of restricted ranges. In those days a great deal of public interest and work in the National Research Council and National Academy of Sciences had been done on this issue. I think what Dr. Mixter means is that now we are up in a realm of magnitude where even with all this forethought that has gone into the problem that it makes one wonder what one can do. I had one other thing, sir.

I don't know whether you want it now or not. Colonel Pickering is right behind me and has some very interesting data which he could present on retinal burns for high-altitude weapons if the committee is interested.

Representative HOLIFIELD. We have Colonel Pickering to follow Dr. Harris on the schedule. If his material will be included in his presentation we will just wait and have him give it all at once.

Dr. HAM. Very well.

Representative HOLIFIELD. Commander, did you have anything to say before you leave the stand? You sat very quietly. The Navy should speak up.

Commander FUGITT. Mr. Chairman, I have been let off very easily. The questions which I was brought along to handle have been admirably handled by Dr. Ham and Dr. Mixter.

Representative HOLIFIELD. We appreciate your appearance here today and we thank you.

Commander FUGITT. Thank you, sir.

Representative HOLIFIELD. Our next witness is Dr. Payne S. Harris. His biography will be included in the hearings. He was assigned to Los Alamos Scientific Laboratory and served there from 1949 to 1953. He has had many assignments in biological research, and was project officer of various atomic and hydrogen bomb tests. He has been adviser to the commanders of these tests. He is now consultant

in nuclear medicine to the Surgeon General of the U.S. Army and to the Surgeon General of the U.S. Air Force, a member of the Scientific Advisory Board to the USAF, and program manager of the Rover project. So we have a man that is eminently qualified to speak to us on the acute effects of radiation.

STATEMENT OF DR. PAYNE S. HARRIS,[1] HEALTH RESEARCH DIVISION, LOS ALAMOS SCIENTIFIC LABORATORY

Dr. HARRIS. Thank you, Mr. Chairman and gentlemen, I believe you all have copies of my prepared statement. I will follow this statement, but I will try not to read it to conserve time. Today I will restrict my subject to the acute effects of nuclear radiation from nuclear weapons on humans, and restricting to acute effects I will consider only effects up to 60 days postexposure. I will not speak of delayed effects due to externally delivered nuclear radiation or delayed effects due to chronically delivered or protracted radiation. Others will speak on those. I will not speak on specific effects, such as surface beta ray burns and effects of internal contamination. I am talking here about whole body effects.

In the acute radiation field it is necessary to restrict one's self somewhat in the characteristics of the source. For the nuclear weapons under consideration here, those from a half megaton to 10 megatons, with a fission-fusion ratio of 1, detonated on the surface, one can characterize the source essentially as follows:

One portion of the source are immediate or initial nuclear radiations from the weapon. These include gamma rays and neutrons. The neutrons appear and disappear within a fraction of a second. The gamma rays appear within seconds and last in their effect until the cloud is out of range.

The second source of interest for acute effects is what I choose to call throwout. This is radioactive debris blown out by the blast wave. I only discriminate between throwout and fallout because this initially deposited radioactive material is not affected by meteorological conditions. Therefore, it gives you a contamination ring rather than an extended contamination outline.

The other source of acute effects from nuclear weapons of these yields detonated in this way is what one may call close-in, or primary

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Had various duty assignments, 1947–49. Assigned to Los Alamos Scientific Laboratory (1949–53). During assignment, did biological research on gamma rays and neutrons. Did radiation dose research on neutrons. Project officer during Operation Greenhouse. Operations officer during Operation Greenhouse. Deputy rad-safe officer and adviser during Operation Buster-Jangle. Adviser to the commander of Operation Ivy. Adviser to test director during Operation Tumbler-Snapper. Project officer and adviser to the test director during Operation Upshot-Knothole. Deputy field command surgeon, FC–AFSWP, Sandia Base (1953–54).

Staff member, Biomedical Research Group, Los Alamos Scientific Laboratory (1954 to present). Alternate group leader, Biomedical Research Group, Los Alamos Scientific Laboratory (1957 to present). Project officer, Operation Teapot. Project officer, Operation Plumbbob. Investigator, Rongelap incident (Project Castle). Consultant to Atomic Bomb Casualty Commission (NAS–NRC), 1956. Consultant in nuclear medicine to Surgeon General U.S. Army and to Surgeon General USAF (1957 to present). Member, Scientific Advisory Board, USAF (1957 to present). Program manager, Rover project (1958 to present).

fallout. I cannot define the boundary conditions exactly for this type of source with respect to acute effect. This depends so much on wind direction, meteorological conditions, that I can't say there will be so many square miles covered. I can only say that in my experience and from information we have, one will not get acute effects of fallout nuclear radiation unless one can see the fallout, either as it comes down or after it is deposited on the ground. So I restrict as a source of fallout that which is visible either while falling down or after it has appeared on the ground.

Representative HOLIFIELD. While this may be perfectly true, it offers no real solution to the problem because the average individual would not know what fallout material looks like any more than he would any other kind of dust. We remember the Japanese fishermen knew something was falling in the way of some type of material, but they did not know what it was. I assume the population would also be in that same situation. There would undoubtedly be a great deal of dust of different types in the air other than radioactive dust.

Dr. HARRIS. Sir, in the case of the conditions as set up in this problem people would be looking for things that were falling down, even at long distances away. What I am saying is that if they see nothing, they don't have to worry about fallout causing acute effects on them.

Restricting ourselves to these sources, I would like to define the acute effects of total body radiation due to gamma rays and neutrons on the human being. I prefer in this case to classify radiation disease into four categories. The four categories that I have preferred to use here are first, no obvious disease. It is important to any physician or any person taking care of people to tell whether they are sick or not—and there are levels of radiation which cause no obvious disease. The second category of the total radiation disease that I prefer to use is disease characterized by response due to the effects of radiation on the blood-forming systems. These effects are rather acute in onset and protracted in length.

The third category is disease characterized by response due to effects of radiation on the gastrointestinal system. These are acute in onset and limited by duration in death.

The fourth category is disease characterized by response due to effects of radiation on the central nervous system. These are hyperacute in onset and invariably terminate rapidly in death.

I separated radiation disease into these four categories because here one is interested in this problem in the handling of casualties. To me these are convenient categories to use for sorting of casualties and the handling of casualties.

Associated with these four categories of effects on humans are a number of cardinal signs and symptoms. We can list these very simply. These are nausea and vomiting, fever or increase in temperature, just general ill feeling and fatigue, diarrhea, bleeding, convulsions, and irrational behavior, and changes in the blood. These last are signs found on laboratory examination. There are changes in the total white count, in the lymphocytes, and platelets. Depilation or loss of hair is connected with radiation. Others are secondary infection, psychological disturbances, and death.

Along with these cardinal signs and symptoms there are two physical parameters that are important in casualty estimation and treat-

ment due to nuclear radiation and its acute effects. The two physical parameters which are most important are dose and time. Time in itself plays an extremely important part in the handling of nuclear radiation casualties. I think we will expand this as we discuss the categories.

The appearance or absence of cardinal symptoms and their importance in prognosis and treatment are extremely dependent on time after the injuring event. On the other hand, dose is the prime determiner of the disease category into which the irradiated individual falls. It is also the principal parameter used for casualty prediction. Before considering a correlation of the category of disease, cardinal signs, and physical parameters, one other item should be covered. This includes the variations in the physics connected with gamma rays and neutrons. I am categorically stating here that a unit dose, whether you call it a roentgen, roentgen equivalent, a rad, a rutabaga, or whatever, from any one of these sources, no matter whether the spectra change from source to source, and for a time of delivery up to 48 hours after the time of the event, all give the same effect. There is no evidence on human beings that will dispute this fact.

I would then like to go to a discussion of the disease categories. I have said there should be a category of no obvious disease. In the consideration of weapons effects, and the handling of the caseloads that will result from any attack, a no disease category is certainly important. Getting down to parameters of this category, there will be no obvious acute effects from doses from zero to 200 rads of initial gamma, initial neutrons, or fallout gamma delivered in periods up to 48 hours post detonation in at least 50 percent of the irradiated population. The facts are that the human data from the various accidental exposures at Los Alamos, Argonne, Oak Ridge, Rongelap, Rongerik, Uterik, and the planned total body exposures conducted at the M. D. Anderson Hospital indicate that no obvious illness occurs at any individual given doses up to at least 150 to 175 rads, and the appearance of symptoms from 175 to 200 rads is trivial.

I have emphasized the term "no obvious disease" since physiological changes due to radiation can be found on laboratory examination of the blood.

Some of the salient features of this category are nausea and vomiting of a mild degree becoming apparent in a fraction of the total population when the dose ranges from 150 to 200 rads. These symptoms are transient until the third postirradiation day, after which they disappear. They appear to have some psychological dependence. No other symptoms appear at all prominent. There is a definite depression of the number of total white cells, lymphocytes in particular, and the total platelets in the blood. This depression in count begins early and shows an abortive rise at about the third week, a minimum of 4 to 6 weeks, and a return to normal in several months. These laboratory findings do not require specific therapeutic measures. Patients in this range do not require hospitalization.

The second category that I noted was disease characterized by physiological responses of insult to the blood-forming organs. From the point of view of the physician, this is the most important category of radiation disease. It is in this category that maximum patient load for the longest total time of hospitalization and maximum possibility

of treatment lie. The dose range of this category extends from 200 to about 1,000 rads. This is also the range from zero to 100 percent death without treatment. One should introduce here some idea of the concept of LD 50, acute LD 50, and what it means.

As it is used in radiation studies in the laboratory, it is a convenient statistical concept used as a guidepost. In the context of acute radiation illness due to acutely delivered radiation, the LD 50 is that dose at which 50 percent of an irradiated population die in a specified time interval, usually 30 to 60 days. It is only a single point, and it tells very little about the response of the entire population. That is the response at which 10, 20, or 70 percent or some other percentage die or otherwise are significantly affected.

These other points are actually more interesting than the LD 50 specifically because they can together give one an idea of the variability of the response among individuals. If this is known, then for any one dose to any one group it should be possible to predict the fraction that would get only minor symptoms, the fraction that would have severe disease, and the fraction that would die. I have only discussed LD 50 and variability for one reason. This is because there has been a wide disagreement among scientists, among physicians, and people in this field, on the value of this specific number. I personally have been a proponent of higher values for this dose. I arrived at this by only considering human cases or what little information we had on human cases. Others arrived at significantly different doses from animal data. However, no matter what particular number is selected, the variability in response is the final determinant of the effort that must be expended in the event of a nuclear catastrophe. It does not matter whether the LD number is 400 roentgens or 800 roentgens. It depends on the response of the entire population.

Generally all investigators agree that the range 200 to 1,000 rads covers the range from inconsequential effects to death within a few weeks. In this category the spectrum of signs and symptoms of radiation disease runs the entire gamut of the cardinal points that I mentioned earlier. There have been myriads of charts and graphs, and there will be myriads of them prepared, edited, and discarded to illustrate the classical radiation syndrome in humans.

One item of importance must be remembered under any conditions. That is, the acute radiation effect is dependent upon two variables: dose and time of exposure. Any discussion of effect must be three-dimensional in nature. Any single effect can only be discussed with the dimensionality in mind. In this fraction or category of radiation disease, the cardinal findings are about as follows:

Nausea and vomiting appear within a fraction of, to a few hours after, exposure. These symptoms are not persistent. It appears that nausea and vomiting are related to the amount of material in the stomach at the time. If the stomach is emptied and not refilled, the symptoms subside even though the dose may be high. Generally the time of appearance of these first symptoms roughly correlates with dose. The earlier the appearance, the higher the dose. The transient character of the response, however, does not allow even rough correlation with dose.

Fever has been suggested as one of the prodromal signs of radiation disease. In the bone marrow injury category, fever is not a

primary indicator of radiation disease. It does not appear early and when it does appear, it is probably related to secondary infection. It is therefore not correlated with dose.

Malaise, or general bad feeling and fatigue, are characteristic of many diseases. In this blood category, these symptoms are prominent to any clinician who investigated the case. The patient just feels rundown or weak and tired. They are not constant symptoms and they may appear in waves with intervals of subsidence. They are not directly correlated with dose or time subsequent to exposure.

Diarrhea is not a prominent symptom in the range 200 to 1,000 rads. A single isolated episode may occur within the first few hours of exposure. It does not persist over these ranges of doses. The incidence noted in the Japanese cases was in all probability due to other factors than radiation itself.

Bleeding is not a prominent symptom at the lower end of the dose range. Frank hemorrhage occurring at around 2 or 3 weeks or later postexposure is a very serious prodromal sign. The presence of small hemorrhages under the skin or an increased bleeding tendency (like pink toothbrush), at 4 to 6 weeks postexposure, are common to exposures within this range.

Remember these symptoms I have gone through here. The symptoms that appear early are transient and don't necessarily have to be treated. This gives you some idea of the therapeutic regimen you have to put the patient through. He is a radiation casualty. If he vomits or is sick to his stomach once or twice over 2 or 3 days, this does not require a lot of treatment. You save your stockpiles of materials until some later time when symptoms that are important occur.

Going on to other signs and symptoms, convulsions and irrational behavior are not exhibited by patients in this category. The changes in the blood are the most prominent as would be expected in a disease characterized by injury to the hematopoietic or blood-forming system. The total white cell count is an index of effect. However, that fluctuates up and down for a few days after exposure even in this range of doses. It then begins to fall rather precipitously and reaches its lowest level from 1 to 4 weeks postexposure, depending on dose. It stabilizes and after a number of days or weeks begins to return to normal. Normal levels are not reached for months postexposure. When you have counts below a thousand per cubic millimeter, one can expect a serious clinical course. It is an indicator of the course of the disease in the individual.

The lymphocyte count, one of the fractions of the white blood cell system, falls rapidly within hours after exposure. In this category the lymphocyte count reaches its lowest level within a few days and stabilizes, after which it takes many weeks or months to return to normal. If it falls to low values, 500 per cubic millimeter, or less, within 24 to 48 hours, the prognosis is extremely bad and probably puts the patient into a fatal category of disease even including treatment.

The platelet count in the blood also falls. It lags behind the lymphocytes. It reaches a minimum a few weeks after exposure and remains depressed for many months. When it does get down to a low level, one would expect then to find bleeding. In most cases we have

seen there has been very little bleeding even though the platelet counts were low and one would expect it.

Loss of hair or depilation appears throughout this entire dose range. It does not occur in any of the other three categories of disease, unless it is precipitated by intimate surface contamination and exposure, such as beta ray contamination sources on the head. It begins to appear the 14th to 21st day following exposure. The hair grows back after a number of months. Below 200 rads it is not seen. Above 1,000 rads, the patient dies before it appears. The severity of the loss of hair may be somewhat correlated with dose.

Secondary infection is the result of the effects on the blood system itself, and the resultant breakdown of the normal physiological barriers to infection. It can occur even under well-controlled conditions, being caused by organisms that are usually nonpathogenic. If severe secondary infection appears, the therapeutic regimen must be closely scanned and adjusted as in any disease. Secondary infection does not appear the day after you are irradiated. It can only be correlated with dose and time on the basis of the blood findings at the time.

Psychological disturbances are important but intangible effects in this category of disease. The actual radiation effect itself contributes little to this type of disturbance.

Death can be a consequence in the region from 200 to 1,000 rad. It is suggested that even with adequate patient care more than 50 percent of the individuals exposed to 700 rads or greater will die within 2 months of the exposure. This is a somewhat lower death rate than has been predicted by others, but analyses of Japanese information, the Oak Ridge cases, and the Yugoslav accident are in reasonable agreement.

It is seen from the above discussion that no one single symptom or sign can be considered indicative of the course of the disease.

Representative HOLIFIELD. Doctor, what would you consider a dose, in terms of roentgens, that would kill 99.9 percent of the population? In other words, you spoke of 700 roentgens in this particular instance. Would you go along with testimony which we have had which indicates that 450 roentgens might kill half of the population and exposure to 600 would kill practically all, or what would your figures be?

Representative HOSMER. You are talking about half the people exposed, not half the population.

Representative HOLIFIELD. Yes; half of the people exposed.

Dr. HARRIS. My answers to this are perhaps more optimistic than others. I would say that for acute death—this is death within 60 days after exposure—one would have to get at least 700 roentgens or roentgen equivalent to kill 50 percent of the individuals so exposed, and would have to get greater than 1,000 roentgens in order to kill 99-plus percent of the people exposed.

Representative HOLIFIELD. You have a very important qualification there, 60 days.

Dr. HARRIS. Yes, sir.

Representative HOLIFIELD. What would your figures be if you extended that to 6 months or a year? In other words, there would be people that would die after the 60 days as a result of a 700-roentgen exposure.

Dr. HARRIS. Yes. There possibly would be people that would die after this time. If one restricts the time interval from 6 months to 1 year after the exposure has occurred, the total number of additional individuals that would die would to me not be statistical. In other words, even in a large population you would not be able to see statistically the small increment of deaths that occur between the period of 60 days and 1 year postexposure. What few additional deaths one would have would not be important in the large mass situation.

Representative HOLIFIELD. You have extended, as your personal judgment, the number of roentgens necessary for death considerably over what the average testimony has been. I wonder at this time how many scientists would agree with you on this extension? We will ask this question again in the panel.

Dr. HARRIS. There will be some on both sides, and they are all friends of mine. I think we are still friends on this. The individuals that I could cite as in support of this are not here at the present time. Perhaps it is just as well. It would consist of individuals from Oak Ridge National Laboratory itself, who were immediately concerned with the Oak Ridge accident, which occurred last fall. There are physicians at Los Alamos who have been concerned with accidents at Los Alamos. I am not sure whether this thesis would be supported by the French investigators of the Yugoslav accident or not. I have not talked to them. Their data indicates that they should agree, to some extent at least, with this thesis.

Representative HOLIFIELD. Could we say that your estimate, as well as other estimates, are still somewhat in the realm of theory, because of the lack of statistical data?

Dr. HARRIS. Yes, sir.

Representative HOLIFIELD. Do you know of any person who has received as much as 700 roentgens whole body radiation and has survived?

Dr. HARRIS. I can only qualify my remark this way. In my own analysis of the dose received by two of the Yugoslav cases, of the total body radiation, those people, as far as I can figure it out at the present time, received an equivalent of 700 rad of mixed gamma ray and neutron radiation or 700 roentgen equivalent or slightly over 700 roentgen, and both of them are still alive and as far as I know in good health at the present time.

Representative HOLIFIELD. Do you know under what circumstances they received it, and if this is an estimate or if it is a measurement?

Dr. HARRIS. That happens to be purely an estimate because the measurements made at the time they received the dose were far from adequate. For that particular dose range we do not have any well-known doses. This is with accuracy of plus or minus 10 percent.

Representative HOLIFIELD. Then we will have to put those cases in the realm of theory rather than in established laboratory clinical data.

May I ask you to go from that to animal exposure in which I assume possibly a mouse or monkey would be closest to man. What has been your experience there, or have you been in this field? Should I ask this of another witness?

Dr. HARRIS. Sir, I can give you my own experience. I think this will come out in later testimony by the people who are to discuss the effect on animals.

Representative HOLIFIELD. We don't want to steal their thunder now. We want to give each fellow the right to his own specialty.

Dr. HARRIS. Insofar as my experience has been concerned with animals, I have exposed mice to various laboratory sources of exposure, to nuclear weapon exposure, acute effect. I have been in on the exposure of monkeys, burros, and pigs to both laboratory and weapons types of things. In all of these cases the total dose to cause death in 50 percent of the exposed groups varies from group to group and from species to species but runs from the neighborhood of 500 rad, total dose, mixed gamma rays and neutrons or gamma rays only, to 700 rad. This is in all of those mammalian systems.

Representative HOLIFIELD. We will go into that in more detail with the specialists.

Representative HOSMER. I understood you to say that your calculations are based on human cases.

Dr. HARRIS. These I cite here.

Representative HOSMER. What order of magnitude of number would that include?

Dr. HARRIS. I made my first estimate on Japanese casualties and data from the Japanese. The biggest error that I have involved in this estimate from Japan is on the dose delivered. I cannot quote errors in dose to individuals of less than plus or minus 30 percent.

Representative HOSMER. You have evaluated them in your own mind, though.

Dr. HARRIS. That is right. It has turned out that it has been awfully difficult to keep the 50 percent death level, the statistical point, to as low a dose as 700 rad, plus or minus 25 percent, in looking at those casualties. At the present time and for the last 2 years there has been a series of investigations going on in an attempt to establish better the dose to individuals exposed in Japan so that we can reduce the error to something of the neighborhood of 10 to 15 percent for a large population of humans. If one looks at the Oak Ridge cases, which are small in number but well documented dosimetrically, one finds no deaths, and the maximum level of dose obtained there was greater than 500 rad of mixed neutron and gamma irradiation. It is on the basis of the response of those people that they believe at Oak Ridge that the LD 50 for human groups with no particular specific therapy, but with patient care, the LD 50 in this case may be as high as 700 to 800 rad.

The Rongelap natives were exposed to much lower doses. The doses are fairly well documented, in the neighborhood of 175 rads. Those individuals, if one looked at them in general and neglected their skin burns due to contact with radiation sources, appeared to be in better health than some of the investigators felt at various times during the weeks they were out there. It is this type of illness. In the Los Alamos cases, we have lower doses.

Representative HOSMER. Doctor, what I am trying to get at, would it be in the nature of 1,000 cases or 2,000 cases or 100? What do you base your work on?

Dr. HARRIS. If one considers the Japanese and includes this, it becomes several hundred cases. If one throws out the Japanese on the basis of poor dosimetric information, then one is down to less than 100 individuals.

Representative HOSMER. I take it the difference between the results found by you and the results found by the people who are proceeding from the animal experiments is the different factor in their case by which they convert to human effects?

Dr. HARRIS. Yes. They are extrapolating from species to species. That is where their uncertainty appears.

Representative HOSMER. Your only case of real doubt in some instances is the amount of dose.

Dr. HARRIS. Yes, sir.

Representative HOSMER. When you come down to the plus or minus 25 percent taken from the 700 rad figure that you have established that could be a variation within the particular individual's resistance.

Dr. HARRIS. It may. This is why I tried to point out previously that as far as these considerations are concerned, it does not make a bit of difference whether the LD 50 in itself is 450 rad or 700 rad. When one is talking about masses of casualties, when one has for acute radiation a change of 100 rad per 25 yards in distance and you have circular errors of the probability of a mile or more, or several miles, and you have vagaries in the winds and the meteorological conditions over which your fallout is going to occur that may vary the dose from point to point by factors of two, it does not make any difference whether the LD 50 is one or the other. What you are interested in is how wide a population you are going to have that is going to have zero effect to 100 percent.

Representative HOSMER. I have just one more question considering all these variables in a pragmatic type of research as against the experimental type and extrapolation. Are there instances that you can refer to in other types of things which would have given us an evaluation of whether your pragmatic approach or the experimental approach produces the most accurate results? Have you been confirmed, in other words, in your procedure with something that happens in an unrelated field?

Dr. HARRIS. No, sir. I am an experimentalist basically myself. This is a little different approach. There may be some system that will show which approach is better. I don't know of any and I am not trying to say one is better than the other.

Representative HOSMER. Thank you.

Representative HOLIFIELD. The Chair must say he was out at the Marshall Islands after the incident there and talked with the doctors in regard to the dosimetry. There was a great uncertainty as to how much exposure these people had. I doubt very much if your data could be very accurate unless you did have the amount of exposure to which these people were exposed, and had control over it. In other words, this is far from a controlled experiment. It is a matter of judgment. I am not saying this for any other reason except to put the facts on the record. As I said, at the beginning, we are in a new field here. We do lack statistical data to establish a firm point as an average. As my colleagues brought out, there would be a variability in the resistance of the individuals to that average. One

person might be easily more resistant than another. Ages and physical condition and other things would have to do with it.

Dr. HARRIS. I have restricted for this category the range from 200 to 1,000 rad saying that here we go from zero percent death to 100 percent death within 60 days or we can statistically extend this to a year if we wish. This is the range of interest as far as handling of patients and treatment is concerned. The LD 50 considerations in these things are all concepts which are to me outside the nature of the business of this particular group.

The third category is the so-called gastrointestinal category where disease is involved with an early involvement of the gut. This occurs in the dose region from 1,000 to 5,000 rads in people. The only reason I bring it up here is because although these patients die or are bound to die, they will have to be treated during the earlier portions of their disease as if they might be in a lower dose level. It is not prior to 6 days after injury that one can definitely place an individual in the dose range of a thousand to 5,000 rad in a category where you would expect him to die, and you only give him patient care until death.

I have gone through the symptoms here that one finds but it is not necessary to do it now. It is written down. The other category that I mentioned for doses above 5,000 rad, is where the effects are on the central nervous system. The reason I bring this up is because patients in the central nervous system category of disease become casualties within 5 minutes after irradiation. This is the only place in acute radiation disease where one gets definite effects where they have to be treated within minutes after the irradition occurs. They die within a number of hours.

Summarizing these, one can say that individuals in the no obvious disease category will require only a minimum of first aid, reassurance. no hospitalization, and no therapy. Similarly those individuals in the central nervous system class will receive only minimal supportative therapy. In fact, it is improbable that many individuals in this category will ever be gotten into medical channels because of the rapid onset of symptoms and general disruption in the areas where such massive doses could be received. Those individuals in the hematopoietic and gastrointestinal categories will account for the majority of the treatable casualties. The patient load will rise sharply a number of hours after exposure is complete. Initially, specific therapy will not be a problem. The patientload will drop at the end of 3 or 4 days and continue to drop during the second week as patients in the gastrointestinal category die. At about 2 weeks postexposure, the patientload will begin again to rise, reaching a maximum at the fourth to sixth weeks. The decrease will then reoccur, dropping slowly over the next several months. With the possible exception of the use of bone marrow, specific therapy will not be in demand until at least the start of the third week, becoming maximum at 4 to 6 weeks postexposure.

The other acute injuring parameters from nuclear weapons detonations will certainly complicate the recognition and handling of nuclear radiation casualties. This is for two reasons. One is connected with the temporal relations involved. Injury due to blast

and thermal radiation is apparent immediately. As has been emphasized previously, injury due to nuclear radiation may not be apparent until hours, days, or weeks following the precipitating event. The second is related to the nonspecificity of radiation disease. A broken leg or a burn is seen and readily identifiable. The cardinal signs and symptoms of radiation disease are nonspecific and may occur singly or in combination in many more ordinary disease conditions.

The expected ratios of combined injury (blast plus thermal, blast plus radiation, blast plus thermal plus radiation, etc.) as well as the ratios of single parameter injury, will also depend heavily on the detonation environment. As far as the detonation itself is concerned, we are restricted to multimegaton surface bursts. These in themselves will change single or combined injury ratios. From the protocol, it is noted that the target areas vary widely in setup and complexity. This also acts on the injury ratios expected.

From a general scan of the effects of these varying environmental parameters, it is possible to draw a few qualitative conclusions on the expected incidence of acute nuclear radiation disease. These may be briefly listed as follows:

1. There will be a paucity of casualties in the very high dose category (central nervous system effect region). The effects of massive exposure will be masked by blast and thermal injury in all individuals irradiated by the initial nuclear and throwout sources. The cases in which the dose was 5,000 rads or greater that do appear will be essentially uncomplicated by blast and thermal injury. These cases will be caused by radiation from very heavily contaminated fallout areas. They also will not appear on the scene until a day or two after the detonation has occurred. It will take this period of time to accumulate enough dose to cause central nervous system symptoms, even if the contaminated areas exceed 1,000 roentgens per hour at a reference time of 1 hour.

2. The majority of acute nuclear radiation casualties will lie in the hematopoietic and gastrointestinal categories. The proportion of these due to initial nuclear and throwout radiation sources will be small. Besides this, casualties from these two sources will be complicated by superimposed blasts or thermal injury, or both. They will thus appear early in medical channels, and the actual radiation injury may not be recognized because of masking effects and the time delay of appearance of specific radiation symptoms. By far the greater proportion of radiation casualties in these two categories will occur due to accumulated dose from fallout. Again, these patients will not appear in medical channels for a few days postdetonation. It is also probable that they will come from areas within the 50 roentgens per hour (reference rate at 1 hour) fallout perimeter.

3. Individuals in the no-obvious-disease category with doses from zero to 200 rads will probably (in all target areas outlined in the protocol) be first to appear for medical aid. Some sorting can certainly be done rather rapidly because the conditions as set up for the exercise predicate late arrival in medical channels for all persons with significant radiation effects, unless there is superimposed blast or thermal injury.

4. The particular local environment of the target situation has some influence on casualty rates and ratios expected. It would be impossible to predict exactly how the acute nuclear radiation casualties would change both in number and type without much more specific target information.

The use of shielding both pre- and post-exposure can operate in only certain directions in influencing acute radiation casualties. First, shielding will tend to increase the ratio of radiation casualties to other type casualties or combined injury. This is because it is generally simpler to shield against blast and thermal than against radiation. Second, shielding will tend to reduce the total number of nuclear radiation casualties. Finally, shielding will tend to concentrate radiation casualties into the category of hematopoietic effect where patient care and symptomatic therapy have the best chance of rehabilitating the individual.

Representative HOLIFIELD. Your full statement will be inserted in the record at this point.

(The statement referred to follows:)

THE ACUTE EFFECTS OF NUCLEAR RADIATIONS FROM NUCLEAR WEAPONS

(By Payne S. Harris, Los Alamos Scientific Laboratory, University of California, Los Alamos, N. Mex.)

I. INTRODUCTION

It is my pleasure to appear before the members of the Joint Committee and review for you a subject with which I have been intimately connected for the past 10 years. As a physicist and as a physician, it has been a fascinating activity—the followup of weaponology—from conception to delivery and the complications of use which (to me) primarily involve the effects on people. In these remarks I will restrict myself to the more immediate (and perhaps more operationally significant) effects and leave the late time results to the capable hands of my colleagues, who also are appearing before you during these hearings. My own subject will include only the acute effects of nuclear radiations from nuclear weapons. I will restrict these few statements to a particular source of effect, to a particular time interval succeeding detonation, and to external total body radiation only. Delayed effects due to acutely delivered nuclear radiation; delayed effects due to chronically delivered or protracted radiation; and specific effects, such as surface beta-ray burns and effects of internal contamination, will be covered by others.

II. CHARACTERISTICS OF THE SOURCE

To investigate the acute effects of nuclear radiations, it is first necessary to define and characterize the sources and conditions of exposure. In these considerations we are restricted to megaton yield, surface-burst weapons with an assumed fission to fusion ratio of 1.0. Under these conditions, the sources of acute effects are initial nuclear radiations, throwout of fission fragments, and fallout occurring within the first few hours.

The initial nuclear radiations of interest are neutrons and gamma rays. They appear as a result of the physics of the detonation. The neutrons appear and disappear within a few thousandths of a second after detonation. The gamma rays from the initial detonation reaction also appear at a very early time. They persist, however, until the actual cloud containing the fission fragments moves out of range.

In any large, surface-type detonation, there is a tremendous amount of radioactive debris trapped with the cast-up surface material. Some of this debris is picked up by the blast wave itself and carried out to rather large distances. This material can be called throwout or very close-in fallout. The important point of discrimination between such material and fallout commonly referred to as long range, local, and tropospheric, is that this portion of the contaminant

source is relatively unaffected by meteorological conditions. High-dose-rate sources very close to the point of detonation may be considered adequately with no particular knowledge of the local weather. The important source of effect from this material is, of course, gamma rays from decaying fission fragments and induced activity in bomb debris and other materials.

The other source of acute effects from nuclear weapons in the megaton class detonated as surface bursts is the gross fallout material carried by the winds many miles from the point of detonation. It is important here to put some limit or "boundary conditions" on the subject of acute effects due to fallout nuclear radiation. I will not attempt to limit acute effects by dose rates, miles downwind, or other such parameters. This is not necessary. It suffices to say that there will be no acute effects due to fallout radiation sources, if the fallout is not visible during its time of fall or after settling on the surface. This statement will be expanded as one gets into the discussion of the effects themselves.

III. DEFINITION OF ACUTE EFFECTS

The acute effects of total body radiation due to gamma rays and neutrons may be conveniently defined by the symptomological and physiological response of the exposed individual. There are ordinarily three categories of radiation disease so defined. For these considerations, I will add a fourth. In brief, the effects are as follows:

1. No obvious disease.
2. Disease characterized by response due to effects of radiation on the blood-forming systems (acute in onset and protracted in length).
3. Disease characterized by response due to effects of radiation on the gastro-intestinal system (acute in onset and limited in duration by death).
4. Disease characterized by response due to effects of radiation on the central nervous system (hyperacute in onset and invariably terminated rapidly in death).

Associated with these four categories of nuclear radiation effects on humans are a number of cardinal signs and symptoms. These may be simply listed as follows:

1. Nausea and vomiting.
2. Temperature.
3. Malaise and fatigue.
4. Diarrhea.
5. Bleeding.
6. Convulsions and irrational behavior.
7. Changes in the blood: (*a*) Total white cells; (*b*) lymphocytes; (*c*) platelets.
8. Epilation.
9. Secondary infection.
10. Psychological disturbances.
11. Death.

The two physical parameters which are most important in any discussion of radiation effects are dose and time. Time plays a part as in no other disease. The appearance or absence of the cardinal symptoms and their importance in prognosis and treatment are extremely dependent on time after the injuring event. Dose is the prime determiner of the disease category into which the irradiated individual falls. It is also the principal parameter used for casualty prediction.

One item that must be considered prior to proceeding to correlate categories of disease, cardinal signs, and physical parameters concerns dose due to different sources. It has been noted previously that neutrons and gamma rays are delivered in very short times directly from the detonation. The gamma ray doses from "throwout" and fallout are delivered over longer periods of time. Also, there are differences in the spectra of the various gamma rays. Do these differences in source and time of delivery change the efficiency of any particular dose in producing an acute effect? Reconsideration of acute radiation effects of the atomic bombings of the Japanese has indicated that the relative biological effectiveness of weapon neutrons to initial gamma rays was probably not significantly different from unity. Similarly, comparisons of effects derived from accident data indicated that source spectral changes and changes in time of delivery (for times up to at least 48 hours) did not vary the efficiency of any particular dose in producing acute responses. Therefore, it may be categorically stated that a unit dose (roentgen, roentgen-equivalent, rad, etc.) from any one of the weapons sources mentioned will have the same effect.

IV. DISCUSSION OF THE RADIATION DISEASE CATEGORIES

It was noted previously that an added category of radiation effect was a loose grouping called "no obvious disease." In any consideration of weapons effects and the handling of the caseloads that will result from any attack, a "no disease" category is certainly important. There will be no obvious acute effects from doses of zero to 200 rads of initial gammas, initial neutrons, or fallout gammas delivered in periods up to 48 hours postdetonation in at least 50 percent of the irradiated population. In fact, human data from various accidental exposures (which includes the Los Alamos, Argonne, and Oak Ridge cases, and the Marshall Island groups) and planned total body exposures conducted at the M. D. Anderson Hospital indicate that no obvious illness occurs in any individual given doses up to at least 150 to 175 rads, and the appearance of symptoms from 175 to 200 rads is trivial. I have emphasized the term "no obvious disease," since physiological changes due to radiation can be found on laboratory examination of the blood.

Salient features of the "no obvious disease" category are listed below.

(*a*) Nausea and vomiting of mild degree become apparent in a fraction of the total population when the dose ranges from 150 to 200 rads. These symptoms are transient and intermittent to the third postirradiation day, after which they disappear. They appear to have some psychological dependence, also.

(*b*) No other symptoms appear at all prominent.

(*c*) There is definite depression of the number of total white cells (lymphocytes in particular) and total platelets. The depression in count begins early, shows an abortive rise at about the third week (in the higher dose cases), a minimum at 4 to 6 weeks, and a gradual return to normal in several months. These laboratory findings do not require specific therapeutic measures.

(*d*) Patients in this range do not require hospitalization.

The second category noted was disease characterized by the physiological responses of insult to the blood-forming systems. From the point of view of the physician, this is the most important category of radiation disease. It is in this category that maximum patient load for the longest total time of hospitalization and maximum possibility of treatment lie. The dose range of this category extends from 200 to about 1,000 rads. This is also the range from zero to 100 percent death, and one should introduce here the concept of LD 50 (acute) and what it actually means.

The term LD 50, as used in radiation studies, is a convenient statistical concept used as a guidepost or normalization point. In the context of acute radiation illness due to acutely delivered radiation, the LD 50 is that dose at which 50 percent of an irradiated population will die in a specified time interval (usually 30 to 60 days). Being only a single point, it tells little about the response of the entire population (that is, the level at which 10 or 20 or 70, or some other percentage die or are otherwise significantly affected). These other points are actually more interesting than the LD 50 specifically because they together give one an idea of the variability of response among individuals. If this is known, then for any one dose to any one group, it should be possible to predict the fraction that would get only minor symptoms, the fraction that would have severe disease, and the fraction that would die.

I have discussed LD 50 and variability of response briefly for only one reason. This is because of the disagreement between investigators on the value of this specific number for human populations. I have personally been a proponent of higher values for acute LD 50 doses. I arrive at higher values by consideration of human cases only (which admittedly have wide uncertainties in the dose values used). Others have arrived at significantly lower numbers by extrapolation to humans from large animal experiments. The main uncertainty here lies in the extrapolation. However, no matter what particular number is selected, variability in response is the final determiner of the effort that must be expended in the management of a nuclear catastrophe. Generally, all investigators and knowledgeable medical individuals in the field agree that the range 200 to 1,000 rads covers the range from inconsequential effects to death within a few weeks.

The spectrum of symptoms and signs in the bone marrow depression category of radiation disease runs the entire gamut of the cardinal points mentioned earlier. Myriads of charts and graphs have been and will be prepared, edited, and discarded to illustrate the classical radiation syndrome in humans. One item of paramount importance must be remembered under any conditions. That is that acute radiation effect is dependent upon two variables, dose and time

after exposure. Any discussion of effect must, therefore, be three-dimensional in nature. Any single effect can only be discussed with the dimensionality in mind.

The cardinal findings for the hematopoietic category of disease may be considered in light of the above. A brief résumé follows.

(*a*) Nausea and vomiting appear within a fraction of to a few hours after exposure. These symptoms are not necessarily persistent. It appears that nausea and vomiting are related to the amount of material in the stomach at the time. If the stomach is emptied and not refilled, the symptoms subside even though the dose may be high. Generally, the time of appearance of these first symptoms roughly correlates with dose. The earlier the appearance, the higher the dose. The transient character of the response does not allow even rough correlation with dose, however.

(*b*) Fever has been suggested as one of the prodromal signs of radiation disease. In the category noted here, fever is not a primary indicator of radiation disease. Fever does not occur early in this dose range, and when it does appear is probably related to secondary infection or some such complication. It is, therefore, not correlated with the dose within this range.

(*c*) Malaise and fatigue are characteristic of many diseases. In this category of radiation disease, these symptoms are prominent to any clinician who investigates the case. The patient just feels "run down" or weak and tired. These symptoms are not constant in that they may appear in waves with intervals of subsidence. They are not directly correlated with the dose or time subsequent to exposure.

(*d*) Diarrhea is not a prominent symptom in the 200 to 1,000 rad dose range. A single isolated episode of diarrhea may occur within the first few hours of exposure. It does not persist over this range of doses. The incidence noted in the Japanese cases was in all probability due to other factors than radiation itself.

(*e*) Bleeding is not a prominent sign at the lower end of the dose range. Frank hemorrhage occurring at around 2 to 3 weeks or later post-exposure is a very serious prodromal sign. The presence of small hemorrhages (petechiae) under the skin or an increased bleeding tendency (pink toothbrush, etc.) at 4 to 6 weeks post-exposure are common to exposures within this dose area.

(*f*) Convulsions and irrational behavior are not exhibited by patients in this radiation disease category.

(*g*) Changes in the blood are most prominent, as would be expected in a category characterized by injury to the hematopoietic system.

> (1) The total white blood cell count fluctuates rather widely for a few days following exposure. It then begins to fall rather precipitously and reaches its lowest level from 1 to 4 weeks post-exposure, depending on the dose. It then stabilizes and after a number of days or weeks begins to return to normal. Normal levels are not reached for months post-exposure. Counts below 1,000 per cubic millimeter are associated with a serious clinical course.
>
> (2) The lymphocyte count falls rapidly within hours after exposure. In this category of exposures, the lymphocyte count reaches its lowest level within a few days and stabilizes, after which it takes many weeks or months to return to normal. If the lymphocyte count falls to very low values (500 per cubic millimeter or less) within 24 to 48 hours, the prognosis is extremely bad and probably puts the patient into a fatal category of the disease.
>
> (3) The platelet count falls in this category. The fall certainly lags behind the fall in lymphocytes. Generally, the platelets will reach a minimum a few weeks after exposure and remain depressed for many months. The fall of platelets does correlate with bleeding, or at least the expectation that bleeding may occur.

(*h*) Epilation occurs throughout this entire dose range of the disease. It does not occur in any of the other three categories unless precipitated by intimate surface contamination and exposure. It begins to appear from the 14th to 21st day following exposure. The hair does grow back after a number of months. Below 200 rads, it is not seen. Above 1,000 rads, the patient expires prior to its appearance. The severity of epilation may be somewhat correlated with dose.

(*i*) Secondary infection is the result of the effects on the hematopoietic system and the resultant breakdown of the normal physiological barriers to infection. It can occur even under well controlled conditions, being caused by

organisms that are usually nonpathogenic. If severe secondary infection appears, the therapeutic regimen must be closely scanned and adjusted as in any disease. Secondary infection can only be correlated with dose and time, on the basis of the blood findings at the time.

(*j*) Psychological disturbances are important but intangible effects in this category of disease. The actual radiation effect itself contributes little to this type of disturbance.

(*k*) Death can be a consequence of the radiation insult in this category. It is suggested that, even with adequate patient care, more than 50 percent of the individuals exposed to 700 rads or greater will die within 2 months of the exposure. This is a somewhat lower death rate than has been predicted by others, but analyses of Japanese information, the Oak Ridge cases, and the Yugoslav accident are in reasonable agreement.

It is seen from the above discussion that no one, single symptom or sign can be considered indicative of the course of the disease. All findings must be considered as a unit. The temporal relationships give some idea of the therapeutic course to be followed. There is at present no universal panacea for radiation disease. There are actually no specific therapeutic agents. Bone marrow has been suggested. The adequacy of bone marrow therapy is not firmly established. Evidence from the Yugoslav accident indicates, however, that bone marrow may be of some use, even when administered a number of weeks after exposure instead of within a few days as previously thought necessary. Antemetics may assist in the control of the transient nausea and vomiting. Antibiotics are of use in the control of secondary infection. Transfusion can be used in bleeding. Our present armamentarium against radiation sickness is certainly nonspecific and in these cases may be bolstered considerably by just good patient care.

The third category of radiation effect that is of importance is the so-called gastrointestinal syndrome. It is called such because of the early and extensive involvement of the gut and the fulminating nature of the disease. The dose range covering this category extends from 1,000 to 5,000 rads, or less. Death is the invariable result. Although effects in this dose range cannot be adequately treated at present, the category remains important because up until the time of death the patient must be under care. The cardinal signs and symptoms do not (early in the course of the disease) predicate that the individual will die. Thus, until a few days or hours before demise, the patient must be handled as those in the second category.

The expected signs and symptoms may be summarized briefly.

(*a*) Nausea and vomiting, fever, malaise and fatigue, and diarrhea are all very similar to the lower dose category initially. After a few days (6, in the one human case on record), these symptoms recur and continue with increased intensity until death a few days later.

(*b*) No frank hemorrhage, convulsions, or epilation occur.

(*c*) The blood changes in the white cell elements are certainly consistent with the high dose end of the previous category. The decline in count becomes precipitous at about the time of reappearance of gastrointestiinal symptoms.

(*d*) As stated previously, death is probably inevitable. In the one case on record, it occurred at 9 days. It would be expected to occur 1 to 2 weeks postexposure.

The fourth category of radiation effect is characterized by central nervous system involvement. In this category, the dose range is 5,000 rads and greater. Patients having this type of radiation disease will die within a matter of hours postexposure. They are in extremis essentially from the time of reception of the total dose. In the one accidental human case on record, incapacitation was complete by 5 minutes or less postexposure. The signs and symptoms shown are noted below.

(*a*) Nausea, vomiting, and diarrhea are early (within minutes), explosive, and also transient.

(*b*) Bleeding, epilation, and secondary infection do not occur. The course of the disease is too short.

(*c*) The total white cell counts show the initial instability and then a decrease. They may increase later, depending on the amount of hemo-concentration that has occurred.

(*d*) The lymphocytes fall and essentially disappear from the blood within hours.

(*e*) Irrational behavior, general collapse, and shock-like symptoms develop within minutes after exposure. Depending on the magnitude of the dose and the supportative therapy given, there may be partial facultative recovery within hours. The time of appearance of recovery, the level reached, and its duration are dependent on the total dose received. At the end of the recovery phase, the condition rapidly degrades. Convulsions, irrational action, and coma precede death by a few minutes to hours.

V. SUMMARY OF RADIATION DISEASE CATEGORIES

The categorization previously discussed was done for ease of application to the weapon effects problem outlined for consideration. It is apparent that individuals in the "no obvious disease" class will require only a minimum of first aid, reassurance, no hospitalization, and no therapy. Similarly, those individuals in the central nervous system class will receive only minimal supportative therapy. In fact, it is improbable that many individuals in this category will ever be gotten into medical channels because of the rapid onset of symptoms and general disruption in the areas where such massive doses could be received. These individuals in the hematopoietic and gastrointestinal categories will account for the majority of the treatable casualties. The patient load will rise sharply a number of hours after exposure is complete. Initially, specific therapy will not be a problem. The patient load will drop at the end of 3 or 4 days and continue to drop during the second week as patients in the gastrointestinal category die. At about 2 weeks postexposure, the patient load will again begin to rise, reaching a maximum at the 4th to 6th week. The decrease will then reoccur, dropping slowly over the next several months. With the possible exception of the use of bone marrow, specific therapy will not be in demand until at least the start of the 3d week, becoming maximum at 4 to 6 weeks postexposure.

VI. COMBINED ACUTE INJURY

The other acute injuring parameters from nuclear weapon detonations will certainly complicate the recognition and handling of nuclear radiation casualties. This is for two reasons. One is connected with the temporal relations involved. Injury due to blast and thermal radiation is apparent immediately. As has been emphasized previously, injury due to nuclear radiation may not be apparent until hours, days, or weeks following the precipitating event The second is related to the nonspecificity of radiation disease. A broken leg or a burn is seen and readily identified. The cardinal signs and symptoms of radiation disease are nonspecific and may occur singly or in combination in many more ordinary disease conditions.

The expected ratios of combined injury (blast plus thermal, blast plus radiation, blast plus thermal plus radiation, etc.), as well as the ratios of single parameter injury, will also depend heavily on the detonation environment. As far as the detonation itself is concerned, we are restricted to multimegaton surface bursts. These in themselves will change single or combined injury ratios. From the protocol, it is noted that the target areas very widely in setup and complexity. This also acts on the injury ratios expected.

From a general scan of the effects of these varying environmental parameters, it is possible to draw a few qualitative conclusions on the expected incidence of acute nuclear radiation disease. These may be briefly listed as follows:

1. There will be a paucity of casualties in the very high dose category (central nervous system effect region). The effects of massive exposure will be masked by blast and thermal injury in all individuals irradiated by the initial nuclear and throwout sources. The cases in which the dose was 5,000 rads or greater that do appear will be essentially uncomplicated by blast and thermal injury. These cases will be caused by radiation from very heavily contaminated fallout areas. They also will not appear on the scene until a day or two after the detonation has occurred. It will take this period of time to accumulate enough dose to cause central nervous system symptoms, even if the contaminated areas exceed 1,000 roentgens per hour at a reference time of 1 hour.

2. The majority of acute nuclear rediation casualties will lie in the hematopoietic and gastrointestinal categories. The proportion of these due to initial nuclear and throwout radiation sources will be small. Besides this, casualties from these two sources will be complicated by superimposed blast or thermal injury, or both. They will thus appear early in medical channels, and the actual radiation injury may not be recognized because of masking effects and the time

delay of appearance of specific radiation symptoms. By far the greater proportion of radiation casualties in these two categories will occur due to accumulated dose from fallout. Again, these patients will not appear in medical channels for a few days postdetonation. It is also probable that they will come from areas within the 50 roentgens per hour (reference rate at 1 hour) fallout perimeter.

3. Individuals in the "no obvious disease" category with doses from 0 to 200 rads will probably (in all target areas outlined in the protocol) be first to appear for medical aid. Some sorting can certainly be done rather rapidly because the conditions as set up for the exercise predicate late arrival in medical channels for all persons with significant radiation effects, unless there is superimposed blast or thermal injury.

4. The particular local environment of the target situation has some influence on casualty rates and ratios expected. It would be impossible to predict exactly how the acute nuclear radiation casualties would change both in number and type without much more specific target information.

The use of shielding both pre- and post-exposure can operate in only certain directions in influencing acute radiation casualties. First, shielding will tend to increase the ratio of radiation casualties to other type casualties or combined injury. This is because it is generally simpler to shield against blast and thermal than against radiation. Second, shielding will tend to reduce the total number of nuclear radiation casualties. Finally, shielding will tend to concentrate radiation casualties into the category of hematopoietic effect where patient care and symptomatic therapy have the best chance of rehabilitating the individual.

Representative HOLIFIELD. Thank you very much for your very valuable testimony. I am sure as we study the material you have submitted there will be a great many things we would like to have questioned you on, but time does not permit us to do so. We are running a little bit behind. Thank you very much.

Dr. HARRIS. Thank you, sir.

Representative HOLIFIELD. The Chair would like to say that during the colloquy with Dr. Ham and his associates the number of physicians in the United States was a matter of question and answer between the doctors and the members. The secretary of the Council on National Defense of the American Medical Association sent a letter up to the chairman.

The staff has included the complete 226,000 in a computation based on the present population, and they come up with a number of 1 doctor to 772 people. This, of course, is an overall figure and does not take into consideration the concentration of doctors in the populated areas that would probably be casualties.

I might ask the staff to see that this letter is inserted in the permanent record at the point of the colloquy rather than at this point. (See p. 251.)

Our next witness is Col. John Pickering. His background and qualifications will be a part of the record.

Colonel Pickering holds the rating of senior navigator, and was recently awarded the Legion of Merit for his contribution in the area of radiation research. He is a past director of the Health Physics Society of America. He is the author of two Air Force training textbooks and approximately 50 scientific papers on radiobiology, weapons effects, and nuclear physics. I believe he is Director of Medical Research for the U.S. Air Force School of Aviation Medicine and Chief of the Department of Radiobiology.

Colonel Pickering, will you please come forward?

STATEMENT OF COL. J. E. PICKERING,[1] USAF, SCHOOL OF AVIATION MEDICINE, RANDOLPH AIR FORCE BASE, TEX.

Colonel PICKERING. Thank you, sir.

Representative HOLIFIELD. Colonel Pickering, you might give us your background and your specific experimental work in this field of effects from protracted exposure very briefly.

Colonel PICKERING. Mr. Chairman, I can be very brief in my remarks in summarizing the experimental data. I had planned to use some slides to illustrate the results.

Representative HOLIFIELD. I think we want to see those slides. I understand they are very revealing. I believe we will go ahead with that, even if we have to carry one of our witnesses over until tomorrow.

Colonel PICKERING. Yes, sir. The topic upon which I was asked to speak was the experimental effects of protracted or long-term radiation. In following up on Dr. Harris' remarks, I would like to go from the 60-day acute effects to those effects which we see over a period of weeks, months, and up to and including 8 years of postradiation in animal experimentation.

I would like to address my remarks to the experimental evidence that we have accumulated and to preface my remarks by stating that nearly 10 years ago there was concern, as there is today, for some of the long-term effects of ionizing radiation. Much of the information we did glean from the casualties from the Hiroshima-Nagasaki, from many of the laboratory experiments, and certain of the accidental exposures that Dr. Harris referred to. The point in question was not the initial rather large amount of ionizing radiation, but really what are the effects of small doses delivered over extremely long periods of time.

For illustrative purposes, I would like to state that experiments begun some 8 years ago were designed to measure the effects of a quarter of a roentgen per hour, 1 roentgen per hour, 4 roentgens per hour, delivered over 16 hours at one time, and fractionated over 7-day intervals for extended periods of time. One of the experiments which I should like to refer to was begun at the Oak Ridge National Laboratory 7 years ago, in which the dose rates which I just spoke of were used. One of the points of extreme concern at this time was, What are the effects or threshold doses which might produce cataracts, shortening of lifespan, increased incidence of leukemia, perhaps temporary

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[1] Born on Apr. 27, 1918, at Bisbee, Ariz. He earned a bachelor of science degree in chemistry and engineering and a master of science degree in chemistry and metallurgy from the University of Arizona. In December 1941, following Pearl Harbor, he entered the Army Air Corps as a flying cadet. Subsequently, he took graduate training in meteorology and was awarded the equivalent of a master of science in 1945. In 1948 he studied toward his doctorate in the field of nuclear physics and chemistry at the University of Chicago.

Assigned first as a research assistant, Department of Biophysics, School of Aviation Medicine, he was in 1949 to establish the radiobiology program at the school, with important collaborative functions assigned from the USAF atomic energy program. Since that time he has headed the program, now organized as the Department of Radiobiology; and in August 1958 he was assigned the additional duty of Director of Medical Research.

Colonel Pickering holds the rating of senior navigator and was recently awarded the Legion of Merit for his contributions in the area of radiation research. In 1955–56 he was a director of the Health Physics Society of America. Colonel Pickering is the author of two Air Force training textbooks, "Student Weather" and "Navigation," and of approximately 50 scientific papers on radiobiology, weapons effects, and nuclear physics.

sterility, and the question which I cannot answer, the genetic effects of these doses.

I would like to illustrate by the first slide one of the points that came from this series of experiments. One of the things that is seen, contrary to the information which Dr. Harris referred to in the acute experiments, is that the effects are much less pronounced in the doses which we have studied. In looking at doses with a total of 30, 120, and 500 roentgens delivered once a week for a period of 6 months, we did not find a mature cataract at all. (Fig. 2, on file with the Joint Committee.) This is the lens of an experimental-animal's eye with only a very few vacuols, and something that would certainly not involve a detrimental effect. (This illustration on file with the Joint Committee.)

Representative HOLIFIELD. Was this whole body radiation?

Colonel PICKERING. Yes, sir.

Representative HOLIFIELD. What animal was it?

Colonel PICKERING. This was the small primate.

Representative HOSMER. The interval was weekly?

Colonel PICKERING. Yes.

Representative HOSMER. The total dose was 500?

Colonel PICKERING. Yes, sir; the highest dose used. If you will go to the next slide, please.

Representative HOSMER. Did you mean 500 a week or a total dose?

Colonel PICKERING. A total dose of 500 over a period of months.

Representative HOLIFIELD. What would this show?

Colonel PICKERING. This shows that there were no mature cataracts. This is one of the first points for which we had concern.

To answer your specific question, animals were exposed as controls, no dose, others exposed to a total dose of 30 roentgens, another group to 120, and a third group 493, over a period of 6 months in their exposure, they have shown at the end of 5 years only a very few opacities. There is no indication to date that these will develop into mature cataracts.

In further looking at the animals and studying the hematological response, we do not find at this date any demonstrable severe biological damage. In the early days, there were changes in the white blood cell picture. These animals have also been exposed to a performance situation in which an attmept was made to study their motor and sensory perception. In no instance have we found that there is a performance decrement when these total doses have been administered over a fractionated period of time in which the interval of exposure was once every 7 days.

It should be emphasized that this work was done under water in the swimming pool reactor at Oak Ridge and there was some concern that we could not make accurate dosimetric measurements. Consequently, a second series of large long-term experiments were set up using a synthetic type reactor with neutrons (Po–Be) and gamma rays (Co^{60}) and an in-air exposure made.

In these instances beginning in 1954, and through to the present date, they were exposed in two different situations. Rather than once a week, they were exposed either every 4th day or every 12th day. They were exposed in each of the exposure days for a period of 16

hours. They were exposed at three different dose rates; a quarter of a roentgen per hour, a half roentgen per hour, or 1 roentgen per hour. This permitted total doses of the neutron-gamma of approximately 78, 156, 316, and 616 rep. (Fig. 2, on file with the Joint Committee.)

It is of interest to note that one group was exposed 40 successive times, another group 20 times, which gives us an overlap of dose where these points are asterisked, using twice as many doses and half the dose rate.

We would obviously accumulate, therefore, the same dose as one with twice the dose rate.

Representative HOLIFIELD. Were these experiments on mice?

Colonel PICKERING. These are on small primates, the rhesus monkey. Again 6 years postradiation we have not found in these animals mature cataracts. Again just a few opacities. There are no blood changes now that are biologically damaging. We have found no instance of leukemia nor have we determined any shortening of lifespan from the administration of these doses of radiation to date.

To contrast this with the remarks of Dr. Harris, the next slide, when we speak of an acute dose of 500 to 700 rep of neutrons delivered to the lens of the eye this is the effect that can accumulate in 13.5 months (fig. 1, on file with the Joint Committee.) A mature cataract. If you will, from the next slide I can show you in acute exposures that the biological effects can be produced. We have produced in many instances a mature or near mature cataract. (This illustration on file with the Joint Committee.)

The point here, however, that I would like to make for the committee is that in no instance, whether it be acute radiation exposure or the protracted exposure, have we seen any biological effects that were serious below a total dose of 200 roentgens. On that point I would like to continue my discussion.

Representative HOLIFIELD. Could I ask you, at that point, to relate this to the background radiation which is generally conceded to be around 7 roentgens over a lifetime of 70 years, and the amount of radiation which has been testified to before this committee as an average of something less than a roentgen from the bomb test buildup of radiation? Then in view of the fact that you are now talking about experiments that relate to 200 roentgens, would you have any comment on whether you can obtain any kind of detectable biological damage with a dose rate as low as 7 roentgens over a 70-year period?

Colonel PICKERING. Sir, I can only answer what our data substantiates, that is to date; and I realize this is only the eighth year of perhaps a 25-year lifespan animal, we do not find demonstrable biological effects. There are other points which will come out in just a moment that may permit an inference in this regard.

Representative HOLIFIELD. When you answered that question, were you speaking of somatic damage and genetic damage?

Colonel PICKERING. Somatic damage. I have no data nor am I qualified to speak on the genetic phases.

Representative HOLIFIELD. You are speaking on the physical damage to the body cells.

Colonel PICKERING. That is correct. If we observe these animals in the next slide, over the entire period over which they have been exposed, one group being exposed every fourth day, the exposures lasting for nearly 200 days, you can follow the blood picture. Let us concentrate on the highest dose represented by the lower line. We find that there is a drop in the leukocyte count during the interim of radiation exposure, but postradiation it returns to what we must conclude from our experience is the normal blood picture.

Four years later we have not found a demonstrable damage at these doses. That is not to say that 10 years from now it will not be manifest. As of 4 to 6 years postradiation they do not yet exist.

Representative HOLIFIELD. How does that compare to the lifespan of man with respect to the animal you are using?

Colonel PICKERING. I am sure that all of us have reasonable doubts. If we take man, whose life is perhaps 70 years, we believe the small primate has a life expectancy of 20 to 22 years. I am not inferring here that you can use a factor of three and scale from monkey to man. I am not certain we know that. That is about the lifespan, sir, one to three. At the time these experiments were going on, opportunity presented itself to look into another type of radiation experiment. For some time and beginning prior to 1951, but my remarks are specific from 1951 to date, radiation had been used in certain select cancer patients as a possible therapeutic agent. It was possible in conjunction with the M. D. Anderson Cancer Hospital to conduct some work in the therapeutic administration of ionizing radiation and to get a feeling for the numbers, that Mr. Hosmer was getting from Dr. Harris, these involved 263 patients. Obviously this is not a large population but it is a group of individuals that were treated.

There were two points that became interesting in this opportunity. It was possible to study effects from, if you will, a fractionated exposure where individuals received 15, 25, or 50 roentgens. One group received this as a total immediate dose. Another group received it in five equal doses. The same for the 25. One 25-roentgen dose within a few minutes. Another one over a period of hours. And also the same for the 50 roentgens.

These individuals in addition to being followed clinically were studied for psychomotor performance. There were tests administered using the two-hand-coordinator and the rotary pursuit which had tremendous statistical significance in terms of the tests, since they had been tried on many thousands of flying cadets. These individuals who received radiation exposure were also taught to work these devices. The idea was that if these types and doses of radiation did produce a performance decrement, perhaps it would be manifest at certain dose levels. Since radiation therapy was not widely used, small doses were at first used in the therapeutic management of these cancer patients.

The first experiment which I have described here on the board in terms of a performance decrement permits the following conclusion. There was no evidence of a psychomotor decrement among the individuals who received these doses of radiation, whether it was adminis-

tered over a period of a few minutes or over a period of a day in five different fractions of dose. In addition there were no clinical evidences of radiation effects.

Representative HOSMER. For the purpose of the record when you were talking with these, were you talking about all of them or the 15 roentgens?

Colonel PICKERING. I am talking here of the 200 patients.

Representative HOSMER. Were you talking about all those doses or just one?

Colonel PICKERING. I would like to combine all of the doses whether they be in single shot or whether they be in the integrated or protracted dose.

Representative HOLIFIELD. This was whole body radiation?

Colonel PICKERING. Yes, sir. There was no decrement in the performance nor in the clinical observations of these patients. There were no suggestions of biological damage. An opportunity presented itself to look at some of the patients 3-years postradiation. I think you should understand that most of these patients were terminal cancer patients, and that there would not necessarily be the whole group alive at the end of 3 years. At the end of 3 years in this followup study, 30 percent of these patients were alive, and that is perhaps about as significant a survival as among those who did not receive any radiation treatment.

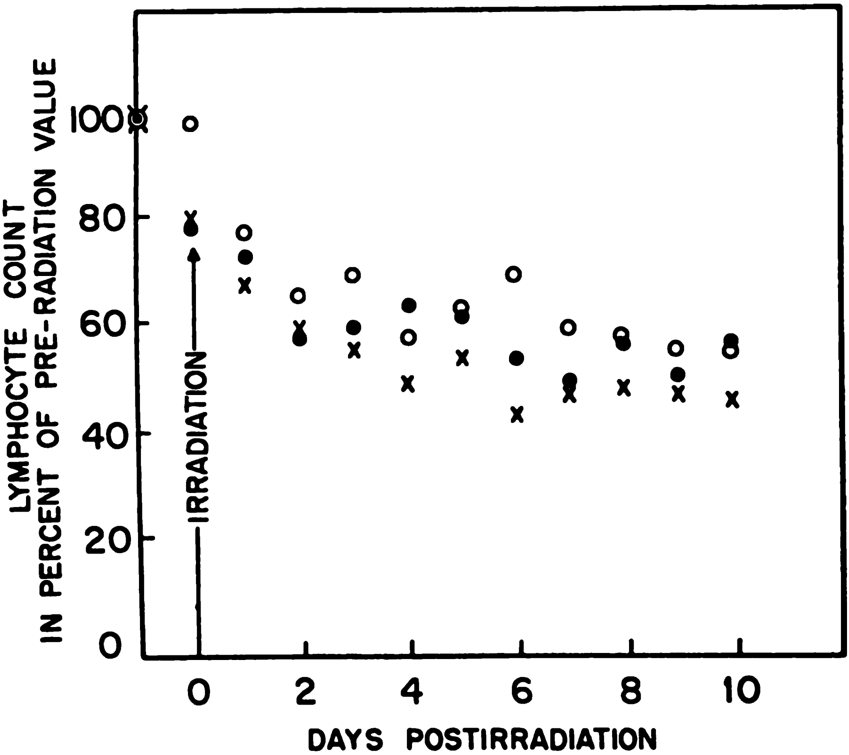
Progressing, then, from this experiment, it became possible to study other patients, and these now are the 263 to which I referred, who were given doses from a control group of zero to 200 roentgens whole body X-radiation. The dose scale went from 25 to 50 to 75, 100, 150, 175, and 200 roentgens.

Again these individuals were followed in terms of performance decrement. In the next slide, one of the things that one sees, looking now at the rotary pursuit, and perhaps you would be interested in what it is, it is a disk like the turntable on a record player, and one is required to follow a dot with a pointer, and to stay on the dot as it goes in its eccentric motion. The control group represents, as you see, a curve, a learning curve. (Fig. 4, p. 292.)

These individuals became better as the days progressed. It was possible to study the individuals 4 days prior to the administration of radiation, and in this particular instance daily for 10 days postradiation. In all instances you see that there is a learning. There is perhaps what one might choose to call a possible decrement at 175 to 200 roentgens in this particular instance, but as the number of patients has increased, we cannot prove this to be statistically significant, and perhaps it is associated with the severity of the disease.

I must point out to the committee that this is one point about which there is some question (200 roentgens). In any event, we did not find a performance decrement in these psychomotor tests and in the clinical observations the individuals below 175 roentgens did not demonstrate any significant biological damage. However, having been followed each day in their blood picture there is the one point to which Dr. Harris referred. There is after the initial rise a drop postradiation in the lymphocyte count. This drop was manifest in all doses from 100 to 125 to 200 roentgens. (See fig. 7.)

FIGURE 7



In observing these patients for a period of several months, there were three other points that perhaps are worthy of the committee's attention. No. 1, the nausea and vomiting that is associated with exposure to ionizing radiation was not sufficiently severe so as to preclude the nutrition of the patient. Secondly, there was an increased bleeding tendency. Thirdly, these individuals when compared to other cancer patients who were untreated had essentially the same life expectancy. If one plots the curve of some 200 individuals stricken with lung cancer and their survival time and compares the individuals with the same disease who received 200 roentgens of whole body radiation, their survival time is identical. So again perhaps all I am trying to say is that radiation did not contribute to an earlier death, whether or not it relieved the condition of cancer, I am not qualified to say.

This study led to an interesting point which I think may come out in the next slide. We have had the opportunity to observe neutron and gamma radiations as it has affected the response of small primates, further there have been opportunities of studying the acute effects from among the Japanese, the nuclear accidents at Los Alamos, the Marshallese and the administration of therapeutic X-radiation in the treatment of certain select cancer patients. If one plots the white blood cell response in all of these types, here is neutron-gamma radiation, beta radiation, X-radiation, delivered over different time periods

and different energy spectrums, the response is not too different, and the minimum depression is about 4 to 5 weeks.

The only reason for showing this is that we would like to feel that as one goes into a long term animal program much information can be taken from the human acute responses that do occur to guide us in the long-term effects, since we do not have chronically exposed human beings at the present time.

Representative HOLIFIELD. Colonel, you will be interested to know that this committee was responsible for raising the appropriation from $2 million to $3 million in the last authorization bill for the purpose of helping in the facilities for experiments on animals along the radiation line.

Colonel PICKERING. Yes, sir. Speaking for our own school, we are grateful to you. If I may continue, moving now from the small primate or the monkey, through the human portion, I would like to go to another series of experiments that are illustrative of this fractionated exposure to radiation and a few of the statements which we may make.

Choosing another specie now, our concern to see if there are specie differences and further if one can relate them from monkey to man, studies were begun on rats. They were given one-tenth of a roentgen per hour, for 8 hours, or, if you will, 0.8 roentgen per day. They were begun on this radiation at age 4 months and irradiated to age 16 months. They were exposed every day for 12 months and followed. We can conclude this, since it has been published and it is of considerable concern, these animals lived longer than the control animals. This effect of extremely small doses of radiation over extended periods of time has produced an increased survival time over control animals receiving no exposure in Dr. Carlson's laboratory, also at Los Alamos, in England, and many other laboratories. It is a point that bears considerable additional work because this could be most important.

Representative HOLIFIELD. Is this an indication, then, that in the cases of small doses of radiation it is apparently beneficial, rather than deleterious?

Colonel PICKERING. I do not feel, sir, that I am personally qualified to say. However, that suggestion has been made by many outstanding scientists. Dr. Mole has demonstrated that certain of the data comparable to what I have just referred, below 10 roentgens per week, the data can be fitted either with a straight line or a curve, and suggests, just as you have asked, that there may be a threshold.

Representative HOLIFIELD. I know one of the facts brought out by Dr. Russell in his mass experiment with mice at Oak Ridge was that the same amount of radiation given over a longer term in smaller but cumulative doses produced much less damage. I think less damage by a factor of four than the same amount given in one mass dose at one time.

Colonel PICKERING. That is correct. There are other investigators who have reported the same. I endeavored to review the literature for you in my introduction so I would not get into controversy with individuals. Dr. Hardin Jones perhaps will have a different opinion in the morning, and I think he has very good merit to his remarks.

The experimental evidence to date in these experiments indicates beyond any question of a doubt that the irradiated animals outlived the controls because the irradiated animals are alive in fact, and the control animals are dead.

Representative HOLIFIELD. Does not this evidence mean that if we want to be intelligent and weigh these factors we cannot jump to conclusions either way? We simply do not have, as yet, enough data to actually prove the case at either extreme.

Colonel PICKERING. As I continue your question will be answered, sir.

Representative BATES. Is there any correlation between extended life in areas which have high natural background radiation? Have any figures been worked out on that?

Colonel PICKERING. I think Dr. Teller and Dr. Pauling have fringed on this. I am not qualified to talk about it. They have discussed people living in Denver or the Tibetan mountains. I don't know whether that is germane to your question.

Representative BATES. That is my question.

Colonel PICKERING. I don't know the answer. I don't know that anyone does.

Representative BATES. You have statistics.

Representative HOSMER. Perhaps the colonel is wondering whether it is a good idea to live longer or not.

Representative HOLIFIELD. Proceed, Colonel.

Colonel PICKERING. Moving then from monkey, man, and rat to the burro. In this particular information which I shall give you, I must qualify it, this is information over which we have cognizance by request but did not do the work. All other information given to this time we have had primary cognizance and are speaking from our experimental data. A band of burros were exposed at Oak Ridge National Laboratory about 9 years ago. There is one particular group in this band of burros that is of interest to us. They were exposed to dose rates of 25 roentgens per week to a total dose of 350 roentgens. The animals involved were 20 in number. To date that group of animals is still alive. They do not show any demonstrable hematologic damage. There are some corneal opacities, but there are as many in the controls as in the experimental animals. So again if you will keep in mind, the doses here and the rates, it will permit me to go very shortly to the only conclusion I would like to make.

Moving from the burro experiments, exposures have been conducted in mice by one of our contractors. We have chosen dose rates of one-third, 1, and 3 rep per hour (gamma radiation). They have been fractionated in dose so that they were exposed either once a day, another group every 3 days, or a third group once every 9 days, to look at fractionation.

In addition one group was exposed for 18 days, another group for 54 days, and a third group for 162 days. If you will, this is protraction of time by a factor of three. These experiments in terms of longevity, as the dose accumulates, show greater mortality, and the greatest mortality exists in the fractionation of every ninth day of radiation. They are only 2 years postradiation and are being followed.

Coincident with this experiment, a gamma ray experiment, was another one done with neutrons, where the assumption was made that the neutron may be biologically more damaging. We assumed that it perhaps may be five times as damaging. Therefore, the dose rates were one-fifteenth, one-fifth, and three-fifths of a roentgen-hour. The intervals were identical.

A point of extreme interest here, mortality accumulated faster in the neutron exposed animals at the 3-day interval than the other two intervals. So one sees in these experiments on both protraction and fractionation effects, that neutrons and gammas are not necessarily the same. It leads to the point that I would like to make, as has already been suggested to the committee, even though there are a considerable series of experiments that are giving us evidence on the effect of long-term radiation, there are many more that need to be done.

In summary, the point I would make is, I think, demonstrated on the last slide. From the evidence we have from among our own experiments, I think my opening remark is still the remark I must stand by. We do not see detrimental biological effects in animals that have been exposed for a period of 5 to 8 years postradiation below 200 roentgens. On this basis we are trying to develop our so-called dose versus clinical effect chart. Below 200 roentgens we need surveillance; there is slight hematopoietic damage, with a drop in leukocytes. We have it from human data on 200 individuals and several hundred small primates, from a colony of nearly a thousand. Although this is not large, it is a large experimental colony to maintain for perhaps 20 years.

With that, those will be my conclusions. To date in the fractionation of dose over the time periods we have available, and the 8 years postradiation, we do not see demonstrable detrimental biological effects in terms of mature cataracts, we have not demonstrated an increased incidence of leukemia in the small primate, we have not found a shortening of lifespan that is attributable to ionizing radiation. These animals are in a breeding colony and whether or not they are temporarily sterile is not manifest, and we are not qualified to study the genetic effects.

Representative BATES. Colonel, how many specimens did you use in this example that you have on the board?

Colonel PICKERING. 17,000 mice.

Representative BATES. 17,000?

Colonel PICKERING. Yes, sir.

Representative BATES. For the nine group?

Colonel PICKERING. That was for the whole total experiment.

Representative BATES. For the 9-day group, how many did you use?

Colonel PICKERING. Approximately one-third.

Representative BATES. This was consistent.

Colonel PICKERING. Yes, sir. As the analysis of variance has now been made in the gamma ray experiments, the mortality increases at the 9-day fractionation period in mice. In neutrons, the mortality is greatest in the 3-day fractionation.

Representative BATES. Do you know of any reason that would account for that?

Colonel PICKERING. No, sir; I don't. I believe the investigators who are with us in this program will take this as their next research step.

Representative BATES. You did not have many deviations from the mean.

Colonel PICKERING. There are deviations, but this finding is statistically significant. By analysis of variance it is a fact on this specie in that laboratory. We based our normal survival time on accepting several thousand animals in January and several thousand animals in July and looking at their normal survival, choosing the worst situation, winter in Chicago, and so on.

Representative BATES. The nine is gamma and three is the neutrons?

Colonel PICKERING. That is correct.

Representative HOSMER. You don't have much of a quarrel with Dr. Harris; do you?

Colonel PICKERING. No, sir; I don't. I have two more points that came from the other questions, and I can be exceedingly brief on them. One is on the LD 50. Information that we have available that Dr. Harris alluded to, but graciously did not discuss, in a study trying to reconstruct, if I may use that phraseology, Hiroshima and Nagasaki, look at dose distributions and perhaps better evaluate the data which are available, small primates were exposed 2 years ago in the weapons effects programs and to date doses of up to 532 rem have not produced an LD 50–30. That is a poor way to state it. (See fig. 9.)

FIGURE 9

MORTALITY

Group	Dose, γ rep	Dose, on^1 rep	Rem	Survival time hr	Survivors	Group	Dose, γ rep	Dose, on^1 rep	Rem	Survival time hr	Survivors
A	562	495	1602	188	0	A	322	286	923	325	0
B	480	436	1396	203	0	B	276	253	807	318	2
C	434	391	1255	213	0	C	252	211	695	357	6
D	395	351	1132	276	0	D	242	185	631	346	5
E	355	315	1017	327	0	E	204	158	536		8
F	320	252	849	356	0	F	187	127	454	549	7
G	285	202	709	423	0	G	169	114	408		8
H	245	213	692	409	3	H	151	103	367		8
I	225	152	544	462	6	I	129	86	310		8
J						J	119	77	281	632	7
Control	0	0	0	0	8	Control	0	0	0	0	8

Representative HOLIFIELD. Will you say what the LD is?

Colonel PICKERING. I think it is above 532.

Representative HOLIFIELD. Lethal dose?

Colonel PICKERING. Lethal dose, 50 percent, 30 days. I base that on having a portion of animals very much alive in the laboratory today 2 years postradiation. So at least for a 2-year postradiation period this does not kill 50 percent of the small primates used. These were adolescent primates.

Representative HOLIFIELD. Was that given in one dose?

Colonel PICKERING. Yes, sir.

Representative HOLIFIELD. 532 roentgens in one dose?

Colonel PICKERING. This was at a weapons effect test. This spectrum of dose extended from somewhere around 1,632 to 135 roentgens.

Representative BATES. Colonel, you said it didn't kill 50 percent. What percent did it kill?

Colonel PICKERING. I can tell you. In this particular 532 roentgens group I have the data. There were eight animals per point, and there are six survivors. It killed 25 percent.

Representative BATES. Haven't many people used the range of 4 to 600?

Colonel PICKERING. Yes, sir.

Representative BATES. So that would fit in somewhere with that experiment.

Colonel PICKERING. That is right. The last point is with reference to retinal burns, Mr. Holifield. In the experiments which were conducted, I can state the following, and I appreciate your earlier remarks that these are open hearings and not classified. There was a news release that retinal burns did occur in the eyes of animals. That is indeed factual. They occurred in the eyes of animals to distances of approximately 300 nautical miles.

Representative HOLIFIELD. Burns occurred in the eyes of animals to distances of 300 nautical miles?

Colonel PICKERING. Yes, sir.

Representative HOLIFIELD. What type of animals?

Colonel PICKERING. They were pigmented rabbits.

Representative HOLIFIELD. How is their blink time reaction in that case as compared to human beings?

Colonel PICKERING. Commander Fugitt is here, and he has the Armed Forces special weapons release. Suffice it to say, and I am sure he would agree with this, that the greatest percentage of the thermal efficiency of the weapon was delivered well inside the blink reflex of the animals. The rabbit has a blink reflex of 200 to 250 milliseconds and the thermal contribution for the most part was delivered in a few milliseconds.

Representative HOLIFIELD. In other words, as far as blink reflex is concerned, the human being would have no more protection than the rabbit has?

Colonel PICKERING. On those particular tests, that is correct.

Representative HOLIFIELD. These were high tests over Johnston Island, were they not?

Colonel PICKERING. Yes, sir. I am referring to the Atomic Energy and Department of Defense release in the Washington Post last week.

Representative HOLIFIELD. That would have had to be slant range, would it not?

Colonel PICKERING. Yes, sir.

Representative HOLIFIELD. Is any of this material classified?

Colonel PICKERING. The details are classified, and they were written and published by our group.

Representative HOLIFIELD. If it has been published it is not classified. You mean it is unclassified.

Colonel PICKERING. It is published in the classified literature of special weapons.

Representative HOLIFIELD. I see. It is written up but it is not declassified to the public yet.

Colonel PICKERING. No, sir. That is why I prefaced my remarks.

Representative HOLIFIELD. Are there any further questions of the colonel? If not, Colonel, you have given us very valuable testimony today, and we appreciate having it very much. This will cause us all to do some studying, I am sure.

(The statement of Colonel Pickering follows:)

I. INTRODUCTION

Exposure to ionizing radiations, when in sufficient doses, can produce in man certain rather specific and well-defined responses. Data obtained from among the peoples of Hiroshima and Nagasaki, the few accidental exposures to Atomic Energy Commission personnel, the recent exposures in Yugoslavia, and extensive laboratory experiments reflect the typical acute radiation responses but not the latent effects from prolonged exposures to low levels of radiation. In this regard, the effects may not be manifest immediately but rather only after a prolonged period of time; hence, extreme care must be exercised in suggesting maximum permissible levels of exposure.

Among the more immediate effects are the decrease in white blood cells soon after radiation exposure: on or near the fifth postradiation day, erythema; at 15 days, epilation with a subsequent regrowth of hair which is often gray in color; and frequently at 30 days, a desquamation and pigment proliferation (1). Lens opacities frequently appear after several months especially after exposure to fast neutrons (1) (see fig. 1). Late somatic effects from relatively large, near-fatal doses of radiation appear as mature cataracts, in certain instances as leukemias, and in shortening of the lifespan. For the most part, however, sublethal doses—less than 460 to 600 roentgens (the acute lethal dose for half of a given population) but greater than 150 roentgens—are required to clearly produce these radiation effects.

So far, consideration has been focused on acute exposure to near-lethal levels, but what of the much smaller doses given intermittently over relatively long periods of time? Experimental data do not substantiate the typical acute radiation responses: certainly there is an absence of erythema, epilation, lens opacification, and desquamation (see fig. 2). The drop in white blood cell count is much less severe; there is, however, a loss in cellularity in the bone marrow, but both of these responses disappear when radiation is removed and repair is allowed to ensue. This is true even when the dose ultimately accumulates numerically to much greater than the so-called LD30–50 dose (2) (see fig. 3).

Even though the acute dose schedules discussed and the even greater protracted doses do not yet demonstrate irreversible biological damage, it is indeed true that these doses may have harmful biological consequences which are more subtle. Such emphasis has been placed on possible effects such as increased susceptibility to bone cancer and leukemia, a shortened lifespan, and harmful mutations that the public has become deeply concerned about them. All genetic information currently available leads to the conclusion that the increase in genetic mutations is proportional to the total dose (3). If this be true, a radiation dose of 2X must be presumed to be twice as harmful as a

radiation dose of 1X; but we still do not know the amount of harm being doubled. Nevertheless, most mutations are harmful and since we have no way of establishing the doubling mutation rate in man except from other species, best estimates indicate that a doubling human mutation rate, after an accumulated dose during a generation, is in the range of 30 to 80 roentgens. This is by far the smallest number yet defined in the development of dose versus irreversible detrimental effects.

So far as lifespan is concerned, much evidence points to the fact that large doses of radiation significantly shorten longevity; on the other hand, very meager data on low doses for very long exposure do not show significant reduction in lifespan. The several mathematical models which permit extrapolation down to very low doses and suggest that life is shortened a few days to a week per roentgen, have been examined recently in light of the available data. In fact, Mole (4) points out that from the very, very few points in chronic exposure to low weekly doses—10 roentgens—three different curves fit the data near equally well and one of them leads to the conclusion that there is a threshold at 1 to 2 roentgens per day below which no shortening of life exists. Other experiments demonstrate that exposure to small doses of radiation increases life expectancy. Warren, in a survey of deaths of 82,441 physicians reported between 1930 and 1954, found that radiologists die on the average 5.2 years earlier than other physicians. Furthermore, nonradiology specialists known to be exposed in a limited way to radiation also show a definite shortening of life but less than that of a radiologist. One might then conclude that exposure to ionizing radiation is the predisposing factor in this shortening of life (5). Lewis (6) in reevaluating the above data concludes that when properly age-corrected the radiologists' longevity is somewhat greater than that of the other groups. This clearly demonstrates that information as to what small doses of radiation will do to a complex organism like the human is still far from definitive (7).

It is now generally agreed that an increased incidence of leukemia can follow acute or chronic exposures to ionizing radiation. By the end of 1956, hematological studies in Hiroshima showed that an increased incidence of leukemia was related to the distance from the A-bomb hypocenter and to the occurrence of the acute radiation symptoms. Furthermore, an elevated case incidence in 1950 has shown no conclusive evidence of decline as yet (8, 9). Leukemia in 1950 killed 3.9/100,000 of our total population over 20 years of age, while from 1950 to 1954 120 physicians died of leukemia, an average annual rate of 11.2/100,000. The death rate for all physicians was about three times that of the adult population. As would be expected, leukemia shows a higher percentage among radiologists. Once again, however, it is difficult to establish a linear dose-response relationship. Evidence strongly suggests a threshold dose or, if you will, a "minimally effective" does (10) of 200 roentgens below which no detectable increase in leukemia incidence has been noted.

Radiation, as we know it today, can produce biologically detrimental responses. It is quite clear, however, that so-called threshold doses or, better, minimally effective doses do occur for every end point of concern with the greatest question surrounding possible genetic effects.

A careful comparison of many human exposures from among Japanese survivors, Marshall Islanders, and groups of cancer patients receiving therapeutic X-radiation reveals certain points in common (see fig. 5). The one point of interest here suggests an individual sensitivity to ionizing radiation. Although there is, in general, a marked variability, in one specific instance, large numbers of persons were exposed under almost identical conditions and these data lead to the conclusion that extremes in susceptibility differ by a factor of about 2. For example, among people exposed to 200 roentgens, the most sensitive would develop a clinical picture of the same severity as that exhibited by the most radioresistant person exposed to a dose of 400 roentgens (11).

II. INFRAHUMAN PRIMATE STUDIES—SCHOOL OF AVIATION MEDICINE

Long-term radiation effects studies resulting from low-dose-rate mixed neutron/gamma fractionated exposures were begun in 1952. Evidence at this early time suggested concern for effects on cataract production, shortening of lifespan, increased incident in leukemia, temporary sterility and genetic effects. Small primates were chosen because of their relatively long lifespan and physiological similarities to man. Three dose rates, approximately ¼ rad/hr., 1 rad/hr., and 4 rad/hr. of 8 or 16 hours' duration were delivered at 7-day intervals for 16 or 8 consecutive exposure periods so that total doses were approximately 30, 120, and 500 rad.

Ophthalmological examinations of these animals to date have revealed no significant abnormalities, although there are some slight changes (see fig. 2). The 30-rad. group showed a slight rise in WBC following exposure, but no significant change in lymphocyte counts. At 120 rad. a slight rise in WBC was noted following the 8th week of radiation with a parallel rise in lymphocytes at the same time. The highest dose group at 8 weeks showed a definite rise in WBC. Bone marrow aspiration showed no significant change. This experiment was complicated by the necessity of underwater exposures, consequently three additional experiments were instituted using a synthetic simulated reactor of Po-Be neutrons and Co^{60} gamma rays in such a way that the exposures could be made in free air. Eight groups of small primates were exposed at approximately 0, ¼, ½, and 1 rad./hr. for 16 hours' duration at 4- and 12-day intervals for 20 or 40 total exposures with a neutron-to-gamma ratio of 1 to 10. This resulted in total doses of 0, 78, 156, 316, and 616 rad. To date there is some slight evidence of ocular abnormalities in the highest dose group which can be attributable to ionizing radiation; however, they will probably not develop into cataracts (see fig. 2). From the psychomotor performance studies it was learned that there was no deterioration in the ability to perform tests which evaluate cognitive functions, motor learning function, and sensory functions after having been exposed to radiation. At 3 years past radiation there is, however, a slight loss in visual acuity in the highest dose as determined by the closed-circle test—a 1° opening cannot be discriminated from a closed circle. Hematologically there was a slight drop in white blood cell count with some loss of cellularity in the bone marrow. Both of these responses disappeared when the radiation was completed and repair allowed to ensue (see fig. 3).

The bone marrow studies in this experiment, when compared to the earlier experiment, may imply that there may not be an additive or synergistic biological effect resulting from combinations of neutrons and gammas. Therefore, a third experiment has been implemented duplicating the dose and dose rate schedules using neutrons in one case and gamma rays in the other—16-hour duration and on a 4-day exposure interval. Data to date indicates small doses of whole body radiation produces a significant reduction of the total leukocyte count with the degree of reduction related to total dose. Furthermore, there is some recovery following the completion of the radiation schedule. To date nothing can be concluded concerning shortening of lifespan or incidence of leukemia, at these dose levels only prolonged observations will disclose or deny these factors.

FIGURE 2

RADIATION CATARACT EXPERIMENTS
A. CHRONIC (PHASE II)

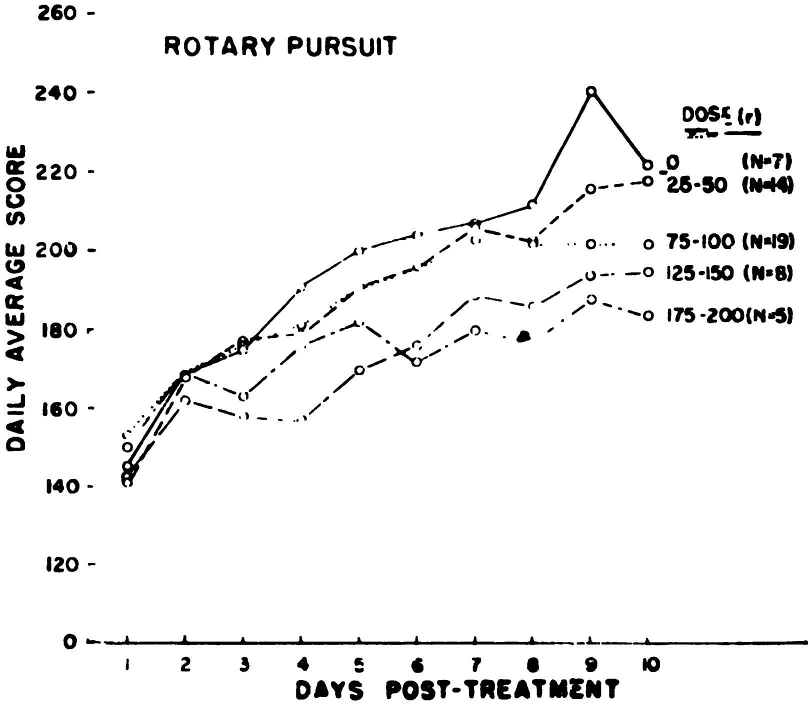
RADIATION TYPE AND SOURCE	DATE OF EXPOSURE	TOTAL DOSE			EARLIEST LENS OPACITIES (MONTHS)	DEGREE OF OPACIFICATION	TIME POST-RAD	POSSIBLE FUTURE PROGRESSION
		GAMMA	NEUTRON	RATIO				
REACTOR SOURCE (PHASE I) OAK RIDGE	OCT 52	0 25 107 493	0 0.74 3.0 11.8	 1/34 1/36 1/42	30	<1+	5 YRS	ARRESTED
SYNTHETIC SOURCE PoBe AND Co^{60} (PHASE II) RADIOBIOLOGICAL LABORATORY-USAF	APR 54	0 70 *140 **140 *284 **280 557	0 8.2 16.4 16.4 32.5 32.5 62.0	 1/9 1/9 1/9 1/9 1/9 1/9	9	<1+	45 MOS	ARRESTED

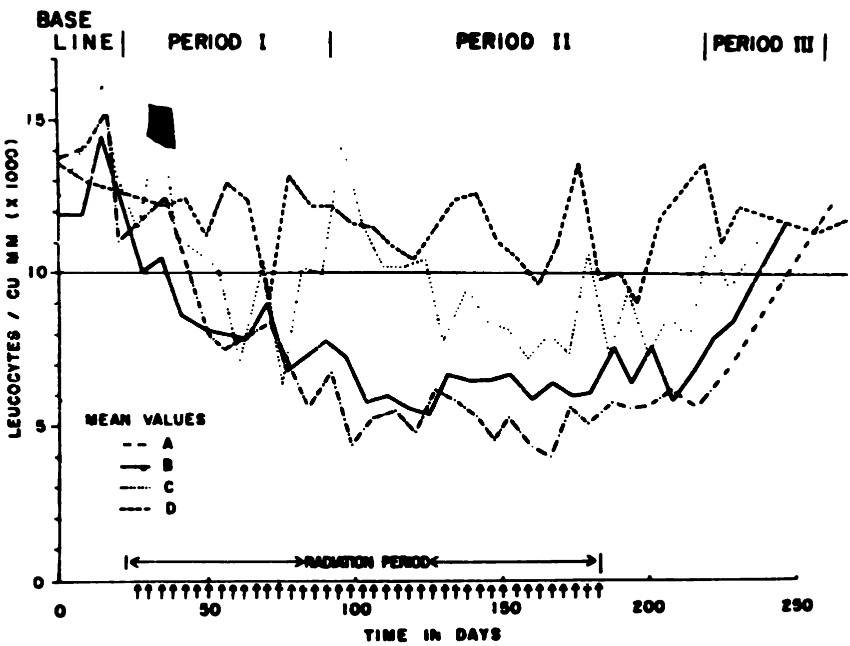
*EXPOSURE INTERVAL EVERY 4 DAYS FOR 40 EXPOSURES
**EXPOSURE INTERVAL EVERY 12 DAYS FOR 20 EXPOSURES

RADIATION CATARACT EXPERIMENTS
B. ACUTE (PHASE III)

RADIATION TYPE AND SOURCE	DATE OF EXPOSURE	TOTAL DOSE	EARLIEST LENS OPACITIES (MONTHS)	DEGREE OF OPACIFICATION (OCT 1955)	TIME POST-RAD	POSSIBLE FUTURE PROGRESSION
FAST NEUTRONS (A) 14 MEV COCKROFT-WALTON ACCELERATOR	15 JAN 1953	250 75 21 6 1.75 .75	13 16-1/2	2-3+ <1+	5 YRS 5 YRS	ARRESTED " IMPROBABLE " " "
" (B)	4 NOV 1953	850 250 75	6-1/2 14 19-1/2	4+ (MATURE 20 MONTHS) 2-3+ 1+	 4 YRS 4 YRS	 ARRESTED IMPROBABLE
" (C)	26 MAY 1955	150 50 15		1+	30 MO	IMPROBABLE
THERMAL NEUTRONS LASL	23 JUL 1953	7500 2500 825	DIED IN 16 WEEKS 9-1/2 14-3/4	 4+ (MATURE 30 MONTHS) 2+	 53 MO 53 MO	 ARRESTED
GAMMA 12 MEV AUSTIN, CO^{60}	30 MAR 1954	3000 2000 1000 500 250	9-10 MO 9-10 MO 9-10 MO 22 MO	4+ (MATURE 30 MONTHS) 4+ (MATURE 30 MONTHS) 3+ 30 MO <1+ 30 MO	 45 MO 45 MO 45 MO	 PROBABLE IMPROBABLE

FIGURE 3


ROTARY PURSUIT
DAILY AVERAGE SCORE
260
240
220
200
180
160
140
120
0
DOSE (r)
0 (N=7)
25-50 (N=14)
75-100 (N=19)
125-150 (N=8)
175-200 (N=5)
1 2 3 4 5 6 7 8 9 10
DAYS POST-TREATMENT


BASE LINE
PERIOD I
PERIOD II
PERIOD III
LEUCOCYTES / CU MM (X 1000)
15
10
5
0
MEAN VALUES
A
B
C
D
RADIATION PERIOD
0 50 100 150 200 250
TIME IN DAYS

III. HUMAN THERAPEUTIC AND EXPERIMENTAL DATA, M. D. ANDERSON HOSPITAL AND TUMOR INSTITUTE AND THE SCHOOL OF AVIATION MEDICINE

It has been established that chemotherapy, for a transitory period only, may relieve pain and cause subjective improvement in cases of incurable generalized tumors, quite frequently even those of low radiosensitivity. Because of its less severe side effects, whole-body X-irradiation has been suggested as a superior method for the palliative treatment of such patients. Is whole-body X-irradiation, here, an effective procedure? If so, how high is the dose that can or must be administered to obtain beneficial results?

To answer these questions, a long-term study was initiated in 1951 and continued until 1956. From the beginning it was realized that significant clinical benefit could be expected, if at all, only at a dose level bordering the clinical threshold dose or clinical tolerance dose, beyond which serious complications might occur. Paucity of knowledge about this important range necessitated cautious exploration beginning at rather low doses. In the range from 15 to 25 roentgens, whole-body roentgen therapy commonly has been used in the management of leukemias; on the basis of this experience, similar small doses were applied first to other, less radiosensitive, generalized tumors. With additional experience gained from careful observation of the patients, the dose was raised in later cases in steps of 25 roentgens. The exploratory phases of the inquiry comprised 233 patients exposed to doses ranging from 15 to 200 roentgens; the final phase consisted of a series of 30 patients who received 200 roentgens. The nature of this study necessitated extensive general, clinical, and laboratory surveillance of the irradiated persons to detect promptly any harmful effect induced by the treatment.

In the first therapeutic study three exposure levels were available: 15, 25, and 50 roentgens, as measured in air. Each dose level was reached either by a single exposure or by five equal fractional exposures separated by an interval of 1 hour. Each subject was given formal test instructions and practice periods on the three testing devices, complex coordinates, two-hand coordination, and rotary pursuit. The data considered do not contain the slightest hint that psychomotor performance was affected by the independent variables under investigation. It is possible, of course, that protracted observation might have revealed important differences, particularly in subsequent rates of progress, but this possibility is generally denied by the second study.

Nine exposure levels, ranging from 0 through 200 roentgens in 25-roentgen steps, were sampled in the second study. Each subject received his prescribed exposure in a single session.

With the possible exception of the 200-roentgens dose, there is no evidence that exposure to ionizing radiation has affected the psychomotor skills in question. Whether this exception is a true radiation effect is debatable (see fig. 4). It could just as well have been a disease effect, for we must presume that the prescribed exposure intensity bore some relationship to the severity of the disease (12).

Clinical observations in the first study 15 to 75 roentgens revealed that treatment was tolerated well in all cases. Three years later 30 percent of the patients were known to be living. Such a survival rate based on clinical experience is not believed to be significantly greater than that expected without whole-body radiation as an adjuvant. In the 100-roentgen group there were some hematologic changes, a significant drop in lymphocytes occurred after the second postirradiation day. And in the 125- to 175-roentgen groups definite hematologic changes occurred during the initial 2-week period, significant drops in both lymphocytes and leukocytes occurred at 4 and 7 days, respectively. At 200 roentgens it was concluded that (*a*) anorexia and vomiting only occasionally reached such a degree as to compromise satisfactory nutrition of the patients, (*b*) a definite transitory amelioration of the disease was produced in three cases and a questionable improvement in several others, (*c*) the bleeding tendency was increased in some of the patients; however, it did not cause alarming accidents, and (*d*) whole-body irradiation did not affect at all the life span of the patients when compared to a similar untreated group of cancer patients (13).

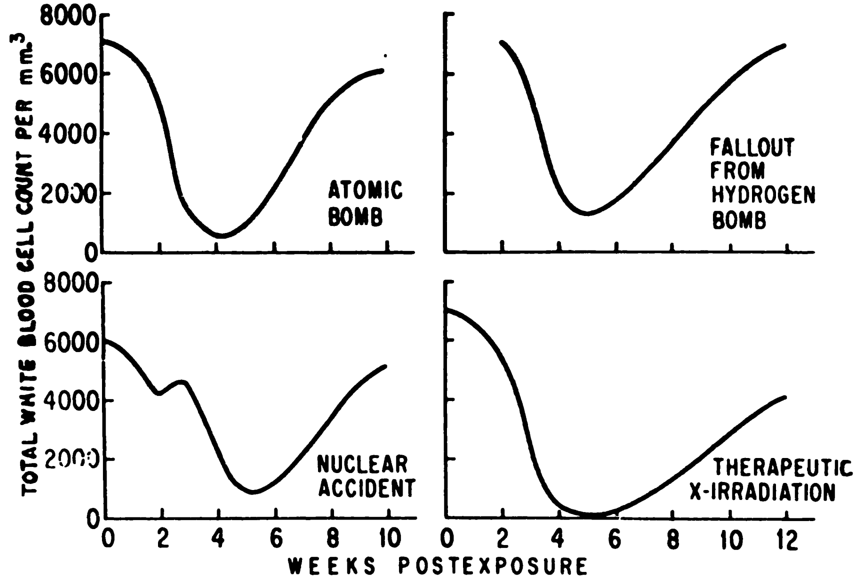


FIGURE 4

Similarity of the leukocyte response in persons exposed to various types of penetrating ionizing radiation. Origin of data is explained in text.

IV. RAT STUDIES—UNIVERSITY OF WASHINGTON AND THE SCHOOL OF AVIATION MEDICINE

Rats living at 25° and 5° C. were exposed to total body irradiation—Co^{60}—at 0.1 r./hr. for 8 hours daily from 4 months to 16 months of age. Irradiated animals at both temperatures had an increased life expectancy, and at 25° C. irradiated animals had a higher resting oxygen consumption.

The following generalizations seem warranted after histologic examination of rat tissues obtained from chronically irradiated and nonirradiated animals raised at 5° and 25° C.

1. There was no histologic evidence of irradiation injury in sections of the adrenal, the bone marrow, the ear (pinnae), the eyes, the kidney, the liver, the lung, the lymph nodes, the peripheral blood, the pituitary, the prostate, the spleen, the tail, the testis, the thyroid, and the tongue of rats receiving 0.84 r. daily for 1 year.

2. The testis was markedly atrophic in rats raised at 5° C. This observation is not readily explained (14).

V. BURRO EXPERIMENTS, UNIVERSITY OF TENNESSEE, AEC FARM, AND THE SCHOOL OF AVIATION MEDICINE

A total band of 59 burros exposed 6 to 8 years ago to Ta^{182} gamma rays are being maintained to study the latent effects of ionizing radiation. Of particular interest is a group of 20 that received 25 r./day for a total dose of 350 r. Typical hematological changes occurred following exposure but in general recovery during the first postradiation year revealed blood values within normal ranges. There are corneal opacities in both control and irradiated animals with no statistical significance. Bone marrow smears also do not reveal significant changes attributable to radiation.

VI. MICE DATA, UNIVERSITY OF CHICAGO, USAF RADIATION LABORATORY, AND SCHOOL OF AVIATION MEDICINE

An extensive mouse program to study the effects of longevity from fractionation and protraction of gamma and neutron irradiation was instituted at the University of Chicago approximately 2½ years ago. Although the data is not yet conclusive and requires additional mathematical analysis, some preliminary observations can be made.

The basic gamma experiment involved three different dose rates of one-third, 1, and 3 rep per hour at 1-day, 3-day, or 9-day intervals (fractionation) with exposure lasting for 18, 54, and 162 days (protraction), and permitted dose ranges to extend from 0 rep, the control group, through 10, 31, 94, 283, 850, 2,551, and 7,654 rep. In the gamma experiment, analysis of variance indicates that there is no significant difference between the survival time of 50 percent of the mice which received their dose over 54 days and those in which the dose was protracted for 162 days. Furthermore, it was observed that the 9-day cycling fractionation produced a significantly greater decrease in mean survival time than the 1- and 3-day fractionations. The 9-day fractionation appears to be more effective than the 1-day or 3-day cycling patterns in causing mortality. For those mice which received doses of less than 283 rep there is not a consistent dose dependent difference in the distribution of mortality from that of the control mice.

In the corollary neutron fractionation experiment dose rates of one-fifteenth, one-fifth, and three-fifths rep per hour were delivered in the same 1-, 3-, and 9-day cycles with the identical number of exposure doses—18, 54, or 162 doses of 0, 19, 57, 170, and 510 rep were obtained. In general, the survival time of those mice which received 510 rep in the 3-day fractionation pattern were considerably shorter than that of the mice receiving 510 rep in the 1- and 9-day patterns. Furthermore, a survival time of the mice in the 9-day pattern is shorter than that of the mice in the 1-day pattern. Analysis of variance indicates that there is no significant difference between the survival time of 50 percent of the mice irradiated for 18 days and 54 days and that of the mice in which the exposure was protracted for 162 days. It is also indicated that the 3-day fractionation pattern does not produce a significantly greater decrease in the immediate survival time than does the 9-day fractionation pattern.

These studies and their analysis are being continued and indeed indicate extensive work must be done before any theory can be formulated on predictability of the longevity response.

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Representative HOLIFIELD. Dr. Newell, we will have to carry you over until tomorrow, sir. We will start with you as the first witness in the morning.

We meet tomorrow morning in the old Supreme Court room. It will be a different room in the Capitol Building. The committee stands adjourned.

(Thereupon at 5:20 p.m., Tuesday, June 23, 1959, a recess was taken until Wednesday, June 24, 1959, at 10 a.m.)

BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

WEDNESDAY, JUNE 24, 1959

Congress of the United States,
Special Subcommittee on Radiation,
Joint Committee on Atomic Energy,
Washington, D.C.

The subcommittee met at 10 a.m., pursuant to recess, in room P-63, the Capitol, Hon. Chet Holifield presiding.

Present: Representatives Holifield, Durham, Price, Aspinall, Hosmer, and Bates; Senators Hickenlooper and Aiken.

Also present: James T. Ramey, executive director; John T. Conway, assistant director; Richard T. Lunger, staff consultant; and Carey Brewer, special consultant, Joint Committee on Atomic Energy.

Representative Holifield. The committee will be in order.

Yesterday the committee received most informative testimony on the various aspects of the biological effects of the hypothetical attack situation posed by the committee. Among the highlights were new data concerning lethal dose rates, acute, and the effects of protracted radiation exposure. We will further explore these topics in our panel discussion this afternoon.

This morning we will continue with testimony concerning the biological effects with particular reference to data on humans. Our first witness will be Dr. Robert Newell, of the Naval Radiological Defense Laboratory. Dr. Newell was formerly head of the Department of Radiology of the School of Medicine at Stanford University, and is a past president of the American College of Radiology.

Dr. Newell, will you please proceed? We have asked Dr. Newell to summarize his testimony this morning because we are running behind. We probably will have to ask some of the other witnesses to summarize their testimony in order to get back to our schedule. If they are not able to complete their statement we will insert the full statement in the record.

STATEMENT OF DR. ROBERT R. NEWELL,[1] U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY, SAN FRANCISCO, CALIF.

Dr. NEWELL. Mr. Holifield, every chance I have gotten for the last several years, I have been lecturing about commonsense. It is hard to be commonsensical about those infrequent sequelae of irradiation regarding which we have to trust our calculations, since they are far below the level of observability. Now we are talking about an overwhelming disaster. This exercise which we have set before ourselves—4,000 megatons of nuclear explosive—is far different from anything we have ever experienced. It is hard to look at this sensibly. In fact, I suspect that most of us don't want to look at it at all.

Previously, we were giving attention to a calculated few individuals that we predicted will die from the effects of the bomb testing. Now we are going to give attention not to the few who die, but to the calculated few persons who will survive. It is a completely different picture.

Yesterday Dr. Harris described the acute syndrome. A person may look all right today but a week later die of his radiation injury.

Now I am asked to talk about some others who will die a year, a decade, or a generation after radiation injury. Most of this is not new to you. When I was a boy I loved to be read to. I don't love to be read to any more. I am going to try to tell you what I think, rather than read you what I wrote. You have had two previous hearings.

The report of the United Nations Scientific Committee on Effects of Atomic Radiation, 1958, is so good that I might well stop right now and let you read the United Nations report. However, there are a few new things which I do want to put extra stress on, and some which are newer than this United Nations report, I think.

Remember we are talking in a new frame of reference. We are talking about the remnants, the moderate percentage of the population that we hope will survive. In this frame of reference a few bad chances in a million, it seems to me, are quite masked by the one chance in two or three of dying in such an attack as we are talking about.

I wish you would look upon these radiation deaths as battle casualties—bombing casualties—even though they are delayed. Leukemia is the delayed death that we have the best quantitative evidence for.

From the exposures in the first days or weeks of a nuclear bombing where 20 or 40 percent of the population is killed, a percent or two of the deaths will be postponed from 1 year to 7 years, and will show up as leukemia deaths.

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[1] Born at Stockton, Calif., 1892. M.D. University of California, 1916, Phi Beta Kappa, Alpha Omega Alpha. Intern and resident, University of California Hospital, 1916 to 1918. Instructor, radiology, Stanford University School of Medicine, 1920, professor, 1932, professor biophysics, 1948, retired 1957. Scientific consultant, U.S. Naval Radiological Defense Laboratory since 1957. Member A.M.A. and other medical societies, Fellow, American College of Radiology (president, 1951), member, California Academy of Medicine (president, 1939). Member, Optical Society of America, American Association for Advancement of Science, Radiation Research Society, American Society of Nuclear Medicine, etc. Member, National Committee for Radiation Protection since 1930, and one-time member of International Commission on Radiological Protection. Member of Radiological Safety Section at Operation Crossroads. Member, Commonwealth Club of California and one-time chairman of its section on eugenics. Chapters in textbooks on radiology, and essays in Glasser's Medical Physics and in professional periodicals.

Married, 1922. Two children. Home, 50 Yerba Buena Avenue, San Francisco 27, Calif.

Additional cases will arise from the continued internal irradiation due to the worldwide fallout. The absolute number will be large because of the large number of people exposed to the risk, but it will be a very small percentage of battle casualties.

There is no doubt at all that radiation is carcinogenic. However, I do not think this is a very serious portion of the hazard. We have not had large enough numbers of men exposed to large enough doses to give us a real quantitative estimate of the carcinogenesis. There will be a few bone cancers from strontium 90.

The other favorite worry about longtime irradiation is the shortening of the lifespan. This is easily demonstrated in animals. Roughly speaking, a quarter of the dose that will kill half of the animals exposed, will shorten their lives on the average perhaps 10 percent. Ten percent of a human lifetime is 7 years. This ought to be observable, but we have not had large numbers of men exposed over their whole body in sufficient dose and followed for a sufficient number of years to get any direct validation of this proposition. You have to take it as a calculated extrapolation from animals to man. Most human irradiations have been of only part of the body. In animal experiments protection of even a quarter of the body, nearly doubled radiation dose required to reach the critical level for death.

I have about 500 records of women who were treated for carcinoma of the uterine cervix. Some were treated with radium and some with radium plus X-ray. The total amount of radiant energy that the latter absorbed into the pelvis, if given all at one time and all over the body, would be a 50-percent lethal dose for man. Of course, it was not so given. It was applied only to the pelvis, and it was spread over a month's time. Those who did not die of their cancer are apparently living out a pretty normal lifespan.

Of course, they have only been under observation for 30 years, and some of them for only 10 or 15 years, so I cannot say what the total lifetime of all of them is. I can only say that they are dying off at a rate which is about what would be expected in a normal population of the same age distribution.

The recovery from the effects of irradiation seems to be extremely complicated. There have been attempts made to find a mathematical formula for it.

For civil defense and for military purposes, and for the ultimate result of irradiation to our American population, I think that we can use a very rough rule, namely, that the effects of today's irradiation wear off at such a rate that they are half gone in a month, with half the remainder gone in another month. This would mean a quarter left after 2 months. However, there is an exception. Some of the irradiation damage is apparently not recovered from. This "irrecuperable fraction" piles up with repeated exposure. Some investigators think that this should be set at 20 percent. In our own laboratory we think it is more nearly 10 percent.

We want to distinguish this flash blindness, which is due to the bleaching of the visual purple of the retina, from retinal burns which are true destruction of the retina. I don't think yesterday's testimony made sufficiently clear that the distance away of the bomb burst makes very little difference in the retinal burn. The image on the retina is

large if the bomb is close; small, if it is far away. But the brightness of the image and the burning intensity are the same.

I think I can make you understand this by pretending to take a picture. The bright countenance of our chairman makes an image on the film. The proper exposure is one one-hundredth of a second. If I should back twice as far away only a quarter of the radiant energy coming from his face would reach the camera—inverse square law—but I would not give four times the exposure. Any one who handles a camera knows you give just the same exposure when you stand here or twice as far away. The secret of it is that although only a quarter as much energy reaches the lens, the image on the film is only one-half as big, i.e., one quarter the area, so the two things balance out. If you are looking at atomic bomb explosions close to you, you get a large burn where the image is on the retina. If you are far away, you get a small burn.

Retinal burns have been produced in animals at very large distances from bomb burst. I think the precise figures are classified.

I would like also to point out that the image on the retina depends upon where you are looking. These two floodlights have their images on my retina, and they are very bright images, but because I am not looking directly at them, they are on a portion of the retina which is comparatively less important. Unless the burn in the retina includes the fovea—the central area of sharp vision—the amount of damage to vision is pretty small. In fact, a person can have a very considerable scotoma—blind spot—outside the fovea and not be aware of it.

I want to add something about genetics. I think perhaps we have taken too much for granted the proposition that every genetic mutation is harmful to the race. We are only here today because we have had mutations in the past. The Darwinian process, survival of the fittest, working over millions of years in the past, has produced a dominant race. This has only been possible because selective mortality has had some variation to work on. The variation has been there because of mutations. It is also not at all axiomatic that the purebred race is the best. There are advantages in organic evolution to what we call heterozygosity. I am sorry to use that big word. It means that the heredity of the cell is mixed between, we will call it, the wild-type gene and the mutant gene, both in the same chromosome, offsetting each other's action, but this in many instances can be demonstrated to be advantageous and not deleterious. Now the chances of any given mutation's being a good mutation are small. You will have to have a lot of chance mutations of all kinds before you have a good one to pick out of the lot. In bread molds a few advantageous mutations appear per billion spores irradiated. You have to put up with a lot of bad mutations in order to get one good one. All the bad mutations that come into the pool of genetic heredity have to be removed later. You can say for sure that every mutation produced by irradiation will have a very large chance of having to be paid for afterward by somebody's dying who might not otherwise have had to die so young.

After such a holocaust as is pictured in the intense bombing of this country and the fallout afterward, there will be a lot of genetic mutations. We should look upon the people who die from the genetic

injuries not only in this generation but also in all the generations to come, as battle casualties. They are the price we pay for not succeeding in avoiding a nuclear war. The human race might still recover, even if half of the people in the next several generations should have mutations so bad as to interfere with their lives. Human fecundity is surely good enough to have twice as many children, so that we could offset the high death rate in the next few generations. Natural—or artificial—selection could thinkably result in an actual improvement in the human race.

Representative HOSMER. Dr. Newell, you mentioned the incidence of leukemia caused by radiation, and I wonder what instantaneous dose rate you take as causing leukemia?

Dr. NEWELL. You mean what dose level I am talking about?

Representative HOSMER. Yes.

Dr. NEWELL. After Hiroshima, a small percentage of those who were heavily exposed enough to produce sickness and epilation, but not enough to kill them immediately, developed leukemia. If you have people heavily exposed, short of killing them, then the survivors will later show 1 or 2 percent of leukemia.

Representative HOSMER. Let me explain my question. You talk about 500 cases of the women who had received in cancer treatment 500 rad dose.

Dr. NEWELL. I have not seen any leukemia in those, but 500 is not a large enough sample.

Representative HOSMER. What I was trying to ascertain is what rad dose instantaneously would be likely to produce a serious leukemia. Is it in the 500 range?

What I was trying to get at is the whole body dose.

Dr. NEWELL. If we figure on the basis of total body exposure such as you might have in war, then about 100 roentgens doubles the leukemia rate: that is, produces an extra 5 per 100,000 per year.

Representative HOSMER. That is an instantaneous dose.

Dr. NEWELL. If you come up to the level of a lethal dose, if this were given in small portions, probably you could put as much as 800 roentgens into a person without killing him; that is, if you spread it over a length of time.

Representative HOSMER. Certainly we know from your cancer treatment cases that 500 rad on a cumulative basis over 30 days will not produce it.

Dr. NEWELL. 500 rads in 1 dose could be expected to give you something between 5 and 10 times the normal leukemia rate. This comes up to not 5 cases per 100,000 per year, but 5 cases in 10,000 per year. This is still a small percentage.

Representative HOSMER. I am talking about the instantaneous dose and the accumulated dose.

Dr. NEWELL. The cumulative dose is more effective only because you can get more in without having the person die of the acute disease. But you can only pile in about twice as much this way. If you gave a person a thousand roentgens of exposure and spread it over a year's time, I don't think that he would die of it. In this way, then, you could get several times as much leukemia without having the person die from the acute exposure.

Representative HOSMER. Do you see any conflict between your present statement and the figures that were given yesterday afternoon by Dr. Harris and Colonel Pickering?

Dr. NEWELL. I didn't think that our figures were at variance. It still is only a small portion of the hazard.

Representative HOSMER. Thank you.

Representative HOLIFIELD. Dr. Newell, in using these terms, we must always remember that the treatment of cancer is a localized dose, and the roentgens used are localized and it is not whole body irradiation.

Dr. NEWELL. I think this is extremely important.

Representative HOLIFIELD. This is very important. There might be some confusion in your remarks that a person could take a thousand roentgens over a year's time in a cancer treatment as against the instantaneous exposure in time of war which he would get all in one shot. Or, if he survived he might get whole body radiation over a long period of time in small quantities. But in the case of cancer and tumor treatment, it is localized on the area where the cancer is, and therefore it does not have the same whole body effect as the type of radiation that we have been talking about.

Dr. NEWELL. I would like to emphasize that again. The same amount of total radiant energy absorbed into the body, if it is put into only a portion of the body, is much less lethally effective than if distributed over the whole body. Also, if the radiation is distributed in time, it is less lethal.

Our patients absorbed 30 or 40 megagram rads in a month of pelvic treatment, enough to match a total body exposure that would be near 50 percent lethal if given all at once.

Representative HOLIFIELD. This would be the same as saying that you could take a pint of blood out of a man once a week until you had a hundred pints, but you could not take a hundred pints at once.

Dr. NEWELL. The difference, Mr. Holifield, is that the recovery from the bleeding is almost 100 percent. Recovery from irradiation is certainly not better than 90 percent. There is always some residual injury from the radiation which is never recovered from. A person can give a pint of blood every few weeks and keep this up year in and year out, but this has no parallel in radiation.

Representative HOLIFIELD. The periodic doses do give the recuperative powers of the body a chance to recover from the deleterious impact of the radiation to a certain extent.

Dr. NEWELL. I would rather put it this way. The unirradiated portions of the body are very powerful curative agents for the effects of the radiation on the part that is exposed.

Senator AIKEN. Dr. Newell, I usually ask very elementary questions and I have one now. Is it possible for radiation to be induced by natural phenomena like thunderstorms?

Dr. NEWELL. There is hardly any produced by thunderstorms, but there is a large amount of radioactivity produced by the cosmic rays. However, its intensity is very small since it is spread all over the world. There is something like a hundred pounds of radioactive carbon made per year in the atmosphere, but it is spread so widely that it requires pretty nice technique to measure it.

Senator AIKEN. The reason I asked that question is that it was reported some weeks ago that a survey of a particular area in northern New York State showed quite a large percentage of deformed children being born. It came to my mind that area seems to have an unusual amount of thunderstorms. I wonder if it is possible to measure the effects of severe lightning? Has that been done to show that there is no radiation induced of any kind?

Dr. NEWELL. I think I can give you something much stronger than that for parlor argumentation. In India, in the State of Kerala, there are about 100,000 people, fisher folk, living on the beaches, and these beaches contain monazite, which has been mined for years for the thorium in it. Many of these villagers have been receiving about 2 r per year instead of a tenth of an r per year which most of us get from natural radiation. They have been getting 10 or 20 times as much as the normal natural irradiation. This has been going on for a couple of thousand years. The Indian Government and the United Nations—I don't know the setup for sure—if the government in Kerala, which has turned Communist, will let them, make a thorough study of these populations to see what the effect of such longtime irradiation at low levels may be. In animals we know that some of the groups which were irradiated constantly or every day for months and months lived a little longer than the ones that did not get irradiated at all. There is a very great deal of scientific uncertainty as to the actual effect of extremely small amounts of radiation.

Senator AIKEN. Thank you.

Representative HOLIFIELD. Mr. Bates.

Representative BATES. Doctor, you indicated that even though the dose may be the same, when it is applied to only a portion of the body, the effect is less than it would have been had it been applied to the entire body.

Dr. NEWELL. Yes. This comes partly because of the peculiarity of the unit that we are using to measure exposure. We measure exposure in roentgens which is exposure. It is like light. I get the same exposure to light if I expose half my hand or if I expose my whole hand. I call it the same exposure. So it is with the radiation which we are talking about. If you want to talk about the total effect of the radiation on the body as a whole, then you have to figure on the total amount of energy that is absorbed in the whole body. We have to make this distinction, and it is confusing to most people. But if you give the same exposure to half the body the body receives only half as much total energy.

Representative BATES. I thought that was the point you made, whole body dose.

Dr. NEWELL. I want to make this point clear. If you talk about the whole body dose, then to get the same total body dose with only half the body exposed, you would have to give twice as many roentgens exposure to half the body. The important consideration is that in order to get the same biological effect in the way of lethality and chance to kill, not only would you have to double the exposure to half the body in order to get the total absorption energy by the body, but you would have to double it again because the protected part of the body would act curatively on the injury of the exposed part.

Representative BATES. That was the purpose of my question. I wanted to know if there was any correlation between the amount of dose and the amount of exposure. You indicated that you have to double it or even more than that on a fraction of the body to be the equivalent of the total amount if exposed to the entire body.

Dr. NEWELL. That is right. Suppose we use absolute numbers. Suppose we talk about exposing the whole body to 400 roentgens. This would be approaching 50 percent lethal dose. If you covered up half the body and gave the 400 roentgens to only half the body, it would not be lethal. If you gave half the body 800 roentgens, the total absorbed energy in the body would be the same as though you exposed the whole body to 400 roentgens. But exposing half of the body to 800 roentgens would not be lethal. In order to get 50 percent lethality from exposing half of the body, you would have to run it up to some 800 roentgens or to some 1,500 roentgens for half of the body in order to have it as lethal as exposure of the whole body to the 400 roentgens. I think putting it in numbers is more understandable. Nobody has done this. As far as I know, nobody has given half of a human body 1,500 roentgens in order to see if it is lethal. We don't do these experiments in man.

Representative HOLIFIELD. Dr. Newell, what do you estimate the average natural background radiation in the world to be?

Dr. NEWELL. It varies somewhat from place to place, but for round numbers I think you can take a tenth of a roentgen a year, of which maybe half comes from inside the body. The potassium in your body yields about 40 milliroentgens per year.

Representative HOLIFIELD. This would be 7 roentgens accumulative dose in a lifetime of 70 years?

Dr. NEWELL. Surely. In a lifetime you accumulate a natural exposure of some 7 r.

Representative HOLIFIELD. To the best of your knowledge, what is the buildup of additional manmade radiation from bomb testing?

Dr. NEWELL. From the bomb testing so far the total accumulated dose here in the United States on the average has been about as much as one year's natural radiation.

Representative HOLIFIELD. In other words, one-tenth roentgen.

Dr. NEWELL. One-tenth of a roentgen in all of the exposure from the bomb testing so far.

Representative HOLIFIELD. And we are talking about whole body radiation now; are we not?

Dr. NEWELL. Yes, surely, because this is quite nonselective. It comes down from all sides.

Representative HOLIFIELD. You have testified that on the monazite sands in India the natives have been exposed to approximately 2 roentgens per year from background.

Dr. NEWELL. In Kerala; yes.

Representative HOLIFIELD. Are there any further questions?

Senator HICKENLOOPER. I have some, Mr. Chairman.

Doctor, I have been interested in your statement on the Kerala area in India and the monazite sands. We have had that up before in this committee. I think it is very significant. Is there any evidence available now that these people who have lived there for thousands of years with 20 times the background radiation of normal areas of the

world have any abnormalities or that their progeny have developed any abnormalities or ailments that might be peculiar to this situation?

Dr. NEWELL. No, there is not. However, shall I say they have not been looked at as closely as this deserves. In order to find this out, you are going to have to examine 100,000 people and examine them quite minutely. In fact, Dr. Gopal-Ayengar, who is the man in India who is the most active in this, thinks and has written that it is nip and tuck whether the effect of this much irradiation is going to be visible in this population. He thinks that if the estimate is correct that one-tenth of the natural mutation rate is due to the natural irradiation and the other nine-tenths of the natural mutation rate is due to other things happening in the body besides radiation, then you won't be able to demonstrate anything in Kerala. However, if as much as 20 percent of the natural mutation rate is due to natural irradiation this means that irradiation is twice as effective in producing mutations as we have usually estimated. Then he thinks that you will be able to see something in the Indian population to show the effect of it.

Senator HICKENLOOPER. As I recall the testimony a year or two ago, we were told that the background radiation around Denver and the Colorado Plateau out west is substantially less than the background radiation on the eastern seacoast.

Dr. NEWELL. The natural irradiation in Denver is quite a bit more than it is in San Francisco. Part of this is due to the fact that Denver is a mile high, so there is a mile less of air interfering or absorbing the cosmic rays—a mile of air is equal in mass to 6 inches of lead. So the people in San Francisco have an extra 6 inches of lead over them to give them protection from the cosmic rays. However, this is a remarkable fact, too. The statistics that I have access to from the Cancer Society and the U.S. Public Health Service indicate that there is more leukemia in San Francisco than there is in Denver, so we are not sure what to think.

Senator HICKENLOOPER. That is my next question because that was brought out a couple of years ago. With increased radiation in Denver and that area, there still was less leukemia than there was on the seacoast where the radiation was substantially less.

Dr. NEWELL. This may only mean that the small effect disappears into the variability of the human race.

Senator HICKENLOOPER. It all adds up to the fact that we don't know much about it, isn't that it?

Dr. NEWELL. That is right. Any time you want to say that the scientists don't know too much about it, you will find me helping you say it.

Senator HICKENLOOPER. Don't misunderstand me. I think the scientists know all there is available to know about it at the moment, but that volume of knowledge still is not too exact or too reliable.

Dr. NEWELL. All we can do is the best we can do.

Senator HICKENLOOPER. Then there is one other thing, Doctor. Do we have any way of telling how many mutations may have been induced through the indiscriminate use of X-rays by incompetent people, let us say, over the many years past?

Dr. NEWELL. We have some pretty fair estimates of it. We have had half a dozen teams doing their best to find out how much gonadal

irradiation is coming from diagnostic radiology. Therapeutic radiology uses large doses, and sometimes the gonadal doses are overwhelming. But there are comparatively few people, and mostly for cancer, cancers occurring mostly in the elderly, and so the number of offspring that have had a chance to be affected is small. So the principal hazard from use of X-ray is in diagnostic radiology.

In England they estimated that the diagnostic radiology was adding about a fifth to the natural irradiation. In America, estimates have indicated diagnostic radiology adding as much as an equal amount to the natural irradiation. This does not go very far compared to the Kerala exposure. Nevertheless, we are looking upon this with great apprehension, or shall we say that we think we ought to be conscientious about it. So the radiological societies are moving to persuade their members to be extra careful, and there is no doubt that gonadal can be much cut down. However, to give you an estimate of the total number of mutations probably produced, this would be on the order of one-tenth of the natural mutation rate. Nobody is sure what the natural mutation rate is. For observable mutations, it is several hundred chances per million per generation. It might be as much as 1 chance in 1,000 per generation, one-tenth of which is due to radiation.

Suppose we give it this generous estimate. It means, then, that if you doubled this, there is an extra chance of 1 in 1,000 per generation of mutation produced by the extra irradiation from medical radiology. This, if you multiply it by 100 million in round numbers, then is 100,000 extra mutations put into the mutant pool carried by the human race. This is not very many. The pool of mutant genes carried in the human race is very large. I used to subscribe to estimates by some geneticists that each one of us carries six or eight mutant genes. The more recent estimates make it one or two mutant genes in each of us. This means, therefore, that scattered over the country there are several hundred million mutant genes around. If you add 100,000 to these in a generation, it changes if only one-tenth of 1 percent. However, if you look at each one, you can figure, as I honestly believe you should, that each induced mutation someday or another will have to be paid for by some person's dying prematurely in a future generation.

Senator HICKENLOOPER. Thank you.

Representative HOLIFIELD. Thank you very much, Dr. Newell. Your testimony has been very valuable to the committee.

Dr. NEWELL. Thank you, sir.

(Dr. Newell's formal statement follows:)

EFFECT FROM PROTRACTED EXPOSURES

SUMMARY OF EFFECT FROM PROTRACTED EXPOSURES

(By R. R. Newell, M.D.)

This time we are looking at the radiation hazard after a large nuclear bombing of the United States and Europe and Asia. We are not speculating on the sequelae of additional irradiation that is small compared to natural irradiation in order to decide whether more nuclear explosions should be foresworn (17). We are speculating on the results of irradiations that run all the way up and beyond the lethal range, in order to decide how many of us will survive and

in what kind of health. We are spared the uncertainties of extrapolation from observation on large doses (demonstrably harmful) to predictions on small doses (so small that we caculate an experimental population of a million (3) required to validate our calculations). But for many of our predictions we shall have to trust an argument by analogy from beasts to man.

My assignment in these hearings is the effects from protracted exposures. I take this to mean irradiations that do not kill within 3 months. I propose to include short time exposures as well as continuous exposures, thinking that others will be dealing rather with the acute radiation syndrome and not following the survivors on into subsequent years of life.

Radiation received slowly, or in divided doses over a period of time is less lethal than when received in a single dose (10). The body is working to recover from the injury done by the first portions of the exposure even while the later portions are piling more injury on top of what's already there. The outcome of the race between recovery and accumulation decides whether the animal (beast or man) succumbs. Many attempts have been made to find a mathematical formula for this (5, 20). Many of them can be made to fit the results of animal experiments by choosing the right numerical constants. In fact it is hard to say that one is better than another, not because they are all so good, but because: 1. A choice of almost any value for the fraction of injury not recovered from can be balanced by a proper choice of recovery rate to make the result come out about right (5). 2. Even in the best experiments some of the animals succumb much sooner than others. These experiments have generally used whole-body exposures. When only part of the body is exposed the effect is less, even for the same total radiant energy absorbed (10).

To predict death in the first weeks or months, we hardly have data or analysis to give a formula much more adequate than the rough general statement: For continued or repeated exposures, recovery goes with a half-time of about a month, but about 10 percent of the injury is practically not recovered from.

Animals irradiated below the lethal level die at an earlier age than normal. The amount of shortening of life span is proportional to the dose (23). The recovery formula above given applies to this as well as to acute radiation death.

Shelters adequate to prevent the acute syndrome may yet leak enough radiation to induce a percentage (or per million) incidence of late sequelae.

For years after the bombing there will be external irradiation from what continues to filter down through the air as well as what accumulates on the ground. To date these external doses from worldwide fallout total about as much as 1 year's natural irradiation. It is mostly Cs^{137} and Sr^{90}, the shorter-lived fission fragments have decayed to low level. Most of it has come down from the stratosphere where megaton bombs put it. The concentration varies with the rainfall. Most is in middle northern latitudes, more in the United States than in Europe. It reaches some 40mc/mi^2 of Sr^{90} and twice that much Cs^{137} in some areas. United Nations report (18) has a good graphic presentation on page 101.

Much has been written about the damage to health from this contamination. Major Dacquisto (4) has summarized the matter for Sr^{90} and gives pertinent bibliography. Plants take up some calcium from the soil and along with it some strontium, although they discriminate against strontium 5 or 10 to 1. The Sr^{90} that falls on the leaves is not mixed with Ca and so is not discriminated against. It has amounted to one-fifth to nearly one-half of the Sr^{90} getting into the milk (in New York). In the production of milk, cows discriminate against Sr somewhat. In the United States most of dietary Ca comes in milk. In Asia it comes mostly from rice. Paddy (unmilled rice) carries Sr^{90} from fallout on the hulls, not mixed with Ca. This offsets the plants' discrimination against Sr from the soil, and the combined discrimination in Sr/Ca reaching the diet may be not far from unity.

Soils vary enormously in their Ca content and somewhat in the availability to plants of what Ca they do hold. Plans to lessen the Sa^{90} hazard by adding stable Sr to Ca to the soil may "backfire" by increasing the total Ca uptake into the body, carrying Sr^{90} along with it (15).

Cs^{137} is quite a different problem because most of its compounds are soluble and it is not retained in the body. The turnover time in man is about half a year compared to some 10 years for St. Cs^{137} acts much like K metabolically, and is spread through the body instead of being narrowly concentrated as Sr is (in the bones).

SOMATIC INJURIES

We distinguish the bad effects on the person exposed, from the genetic effects which crop out when they chance to in subsequent generations.

The recognized bad somatic affects that emerge a long time after irradiation are usually listed:

1. Leukemia (and aplastic anemia).
2. Carcinoma and Sarcoma.
3. Shortening of the life span (premature aging).
4. In some animals cirrhosis of the liver and nephrosclerosis (a kind of Bright's disease) have been produced by irradiations. I know little about such sequelae in man.
5. Cotaract.

These things are not news to you. They are well presented in previous congressional hearings and in the Report of the United Nations Scientific Committee, with references to the original literature. I'll put down here some of the aspects that appear of prime importance in the framework of the war picture we are here considering.

LEUKEMIA

Many kinds of animals are subject to leukemia, and some have been chosen for laboratory experiments because of the ease with which leukemia can be induced in them by irradiation. Most experimental leukemias are lymphocytic. Most leukemias in man after irradiation have been granulocytic. We think they are not the same disease. We think acute leukemia such as has appeared in a disproportionate number of infants and children after irradiations in utero, is still a different disease. Some leukemia in animals (notably in chickens) is due to an infection (filterable virus). This has not been demonstrated in man. In fact a leukemia patient did not transmit his disease to another patient with whom he exchanged blood continuously for many hours.

The best quantitative data on leukemogenesis in man are from X-ray therapy for spinal arthritis. These are partial body exposures. In animals, such are less efficient than total body exposures. Scientists do not agree whether the data on 13,000 patients that developed 37 cases of leukemia fit a linear or a quadratic relationship better.

The people of Hiroshima and Nagasaki are the only numerous groups receiving total body exposure. In them the dose has to be calculated from indirect evidence. We can say with some certainty however that the chance of leukemia's being induced by a large sublethal single dose is 1 or 2 percent (24). This amounts to saying that a few of those killed by radiation had their deaths postponed a few years.

The leukemias begin to show up a year or two after the exposure and appear most frequently 5 to 8 years after exposure. The tendency is nearly worn off by the 7th year (X-ray cases) or the 10th year (bomb cases).

In the exigencies of postbombing life the decision to risk a sortie from the shelter at a cost of 100 r total body exposure will be but little weighted by the small extra chance of getting leukemia a few years later.

CARCINOMA

The carcinogenic potential of radiation is obvious. A large number of cases of skin cancer have been reported following intensive X-ray exposures, and also after habitual exposure to small amounts of X-ray or radium. The latent period is long—two decades, even four decades. Yet radiation cancer is still uncommon among all the cancers that we see (9). Oldtime radiologists, as a limited group of unusual exposure, did suffer a considerable incidence and mortality from cancer of the hands. The only other group with a high cancer incidence worked in the uranium mines of Saxony. They were not then so recognized, but we are now convinced that the deaths among the lifetime miners were about 50 percent lung cancer (from breathing radon diffused out of the rocks).

The high concentration of radioactive particles in early fallout is soon ended. It is doubtful if the inhalation hazard is an important part of the general radiation hazard after a bombing. The blood changes in the Rongelap natives (now nearly recovered from) have not been appreciably exacerbated by the small amount of radioactivity that got inside their bodies. In shelters the problem of breathable air will arise not from fallout, but from congested occupancy.

The concentration in worldwide fallout is extremely low. After the total of 4,000 megatons assumed in producing the Weather Bureau's illustrative charts, the worldwide stratospheric fallout might produce continuing activities in the atmosphere comparable to the natural radon activity there. In air sampling to measure the fallout concentration it is customary to wait long enough for the radon daughters to decay before attempting to count the fission product activities caught on the filters.

SHORTENING OF THE LIFESPAN

Single large doses of radiation do shorten the lives of experimental animals. In rats and mice a quarter of the lethal dose given in youth appears to shorten the average lifespan by 10 percent. In man there are no observations adequate to indicate the life shortening from whole-body irradiations. The often quoted value of 10 days' shortening for every 1 r. exposure is a speculation. To put it conservatively at 1 day per roentgen is equally a speculation. Even with animals of very uniform stock the usual experimental groups of 30 or 40 are too few to give dependable measure of life shortening (4, 5, 10). To validate such speculations in man promises to remain unattainable. Although reports of acquired adaptation to irradiation are not very convincing, yet it has been observed several times that animals continuously exposed to a fraction of a roentgen a day lived longer than the unirradiated controls.

I (14) have compared the survivals of women cured of cancer of the uterine cervix by radium treatment (about 3 megagram rads) with the survivals of those cured by a combination of radium and heavy pelvic X-irradiation (about 25 megagram rads). These treatments extended over a month's time. The same total energy absorbed from acute whole-body irradiation would have been about one-half or one-third of a lethal dose. Yet the two groups appeared to be following about the same age-corrected mortality rate, not significantly different from the 1940 U.S. census.

CATARACTS

A total body dose of gamma rays sufficient to produce cataracts would probably be lethal. Neutrons are exceeding efficient to produce cataracts, but survivors of large bombs are unlikely to have received a neutron dose.

CHRONIC EXPOSURE

The fallout maps prepared on assumption of 4,000 megatons, half fission, show worldwide Sr^{90} fallout across the United States up to 1 c/mi (2), and streaks of local fallout up to 300 curies, one of which might include Washington. This localized contamination is several thousand times the general average Sr^{90} level in the United States, although the fissions presumed for the example are only 100 times the fissions to date. The Cs^{137} can be taken as about twice the Sr^{90}. The present total body and gonadal irradiation from Cs^{137} is about 2 percent of that from the natural K–40 in the body. After the bombing one could expect 100 times that much generally, but up to 10,000 times in the hotspots. At best, one would predict less than double the natural level of irradiation. At worst 2 or 3 times the presently accepted MPD for persons employed after age 18. It might be necessary to colonize such areas with people over 50 years old. In those areas where measurement shows the radiation field to be tolerable for a few hours' occupancy, a planned attack on the problem ad hoc, as by plowing, scraping, etc., may reduce the ambient gamma field to the habitable level (15). Inspection of food for radioactivity should make it possible to hold down the accumulation of Cs^{137} and Sr^{90} in most people. If some do get 100 times as much as seen in young bones today, the Sr^{90} will still be below the least that has been found carcinogenic in mice (7, 8). If man's longer life makes him 10 times as vulnerable as a mouse, it appears likely that the Sr^{90} after the nuclear attack presumed will finally rise to produce an occasional tumor.

It has been suggested that the very uneven distribution of Sr^{90} in bones will give "hotspots" of highly carcinogenic effect. If one assumes that the effect is proportional to the concentration, then the increased carcinogenicity in the hotspots is just balanced by the reduction in volume of bone marrow at risk (1).

GENETICS

You will hear about genetics from Dr. Neel. I wish to speak about the Russells' (19) evidence that protracted irradiation of spermatagonia is less effective in producing mutations than single-dose irradiation is. Their data are persuasive, but the conclusion is hard to fit into our picture of the mechanism of inheritance. Such a fourfold safety factor for low-exposure rates is very welcome when facing continuing radiation hazards.

In the threat of nuclear warfare we face the expectation of a great influx of mutations into our human heredity. We'd like to put a better face upon it. Not every geneticist takes an increase in mutations as an unqualified evil (6). Aside from the one-in-a-billion chance of a really beneficial mutation, we have to realize the unmeasured advantages of heterosis (genes matched to mutant genes instead of paired with identical "normal" genes). We should also realize the evolutionary value of genetic variability. Without variability we should not be here, because there'd have been nothing for organic evolution to work with—nothing for Darwinian selection to choose among. It's true that every unsuccessful mutant requires a premature death to get rid of it again. But such mortality, in measured degree, may be necessary to keep our human race adapted to the world we live in.

I would like to stand back and look again at the nuclear bombing here assumed. The attack pattern presents a widespread radiation hazard that is initially lethal for many persons and that is ameliorated to mere sickening for those under some protective cover. In shelter it can be completely safe. Outside it diminishes in some areas to nonlethal and with time to manageable. It is doubtful whether after such an attack it will come down even in many years to our present maximum permissible limits for more than a minority of the population. The casualties on this field of battle will be falling for years and generations to come.

Fortunately the human race has the power to go on, leaving the fallen behind and cleansing itself gradually of the genetic injuries inflicted. We can even draw an ideal picture of the survivors of worldwide irradiation, emerging as a bigger, stronger, wiser, gentler, healthier race than would otherwise have developed. The price would be: A large or major fraction of the population killed, or dying within a few months; survivors carrying many radiation-induced mutations; high infant and adult mortality for many generations, straining the naturally high fecundity of women to maintain the population. Then as populations begin to build up again, would come the opportunity for conscious eugenic management, with large families limited to parents of superior native endowments.

STATEMENT ON EXTERNAL BETA RAY

If local fallout settles on the body surface, as it did on the Rongelap natives, beta rays will add a superficial injury to the deep injury from the gamma rays. Animal experiments at USNRDL (not yet published) indicate that external beta and gamma exposure should not be added together (the way one properly adds gamma and neutron ray doses). A beta exposure so large as to produce a severe burn does increase the lethality from gamma irradiation, only in the same way that a comparable heat burn would.

It takes about 2,000 rads of beta dose in the basal layer to destroy skin epithelium. The percentage of animals that die from such a lesion depends on the percentage of skin area affected, just as in the case of heat burns. Increasing the dose to 100,000 rads on the same area makes the lesions very much slower to heal, but does not increase the percentage of animals that die.

Carcinoma

Beta rays, like gamma rays and X-rays, are carcinogenic. In rats tumors begin to grow in the irradiated skin after about 6 months—long after the skin is smooth and hair has grown in again. Some of the tumors are cancerous. The incidence of tumors increases, of course, with the area irradiated, and with the dose up to about 1,000 rads. Doubling that dose, however, reduces the tumor incidence very much. Two doses of 1,000 rads to the same area, given a week apart, produce tumors in almost as many rats as a single 1,000 rad dose does. Still larger single doses reduce the tumor incidence even further. Apparently the excess dosage merely kills off injuried epithelial cells that if let grow would have shown an induced likelihood to cancer. Recovery in a week is so good that the potentially cancerous cells are but little more vulnerable than the normal cells.

In man the carcinogenic effect of such beta irradiations has not been reported. The areas so treated are almost always small, in contrast to the broad areas treated for acne, swollen glands, Graves' disease, etc., and the radiologists' and dentists' hands that have provided the numerous reported instances of X-ray cancer. The patients that I have treated with beta rays (of P-32) over large areas have been under observation only a few years, not long enough for cancers to have appeared, perhaps.

CONCERNING SHELTERS

Warfare changed after Hiroshima, and has changed yet again. Nuclear strategic bombing if massively engaged in will be locally destructive beyond what we shall predictably protect ourselves against. Totally destructive blast and thermal radiation will extend far beyond the reach of the prompt gamma and neutron rays. No use gazing fascinated on the numbers that will be killed. The place for our attention is the remnants. The remnants have to live awhile without the organization of our civilization and in spite of radiation from the fallout.

The basic necessities first:

Air

It would be well to have gas masks, but it appears unlikely that people will buy them or that Government will supply them to everybody. It is doubtful whether people would use them effectively without training and drill, and appears more doubtful that they would accept the training and drill if masks and classes were provided. Anyhow, the real problem is not airborne radioactivity but rather vitiation by the human occupants.

Radioactive fallout breathed in, is unlikely to be lethal except over limited areas. The people on Rongelap show quite unimportant body burden of radioactive materials breathed in during fallout that gave them an estimated 175 r. of external exposure.

Bacterial and chemical strategic attacks are a potent possibility and in the latter case masks could be critical for survival.

Water

To drink is next most imperative. Thirst won't kill in less than 30 hours if one is quiet, even in hot weather. But canned foods and bottled beverages will be accessible to most survivors even with no foresight in providing them. Every home, nearly, has a storage water heater. This holds water for a family for weeks, if some person foolishly frightened about skin contamination, doesn't use it to take a bath.

It is most unlikely that the water in city supplies, tanks, pipes, and reservoirs will be contaminated by even the heaviest fallout to make a lethal concentration reach the tap, and not very likely that it will be harmful (in the context of war survival).

Food ought to be stowed in packages and cans in basements and in the trunks of automobiles to supply each family for a couple of weeks. But two weeks without any food is not lethal. As the need for food becomes imperative the fallout activity decays, and sorties to get supplies involve less hazardous exposure. The short-time food problem looks like an inconvenience at worst (2, 7, 13, 16, 22). The real problem of sustenance for the first months will be to reorganize the transport and delivery of food.

The problem of disposal of excrement during the first few days when a trip out of the basement to the flushing toilet gives too much exposure, has had too little courageous consideration. It will not be solved generally until we overcome our prudery, and devise and practice techniques that have enough holding capacity and can control the odor to tolerable degree. Many shelters and many people practicing the use of them (for the experience) would be the effective program to undertake.

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Representative HOLIFIELD. Our next witness is Dr. Clayton S. White. I have just been informed that he has just arrived by plane. We will invite him to the witness chair at this time. Dr. White has served as chairman of the AEC Ad Hoc Committee on Blast Biology from 1958 to the present time. He is chairman of the Aeromedical and Biosciences Panel of the U.S. Air Force Scientific Advisory Board. He is at present director of research in the Lovelace Foundation. I am going to put his biography in the record at this point. It is a very notable one.

Representative HOLIFIELD. Dr. White, we realize you have had to adjust your own program to come to this meeting because of other duties, and the committee wishes to express its appreciation to you for coming here today. We felt that your particular testimony on blast effects on humans is something that should be in this permanent record. That is why we have been rather insistent that we get this testimony. We appreciate your coming.

STATEMENT OF DR. CLAYTON S. WHITE,[1] DIRECTOR OF RESEARCH, LOVELACE FOUNDATION FOR MEDICAL EDUCATION AND RESEARCH, ALBUQUERQUE, N. MEX.

Dr. WHITE. Thank you, Mr. Holifield, members of the committee and ladies and gentlemen. Initially I wish to make a few preliminary remarks. First, it is a pleasure to express my appreciation to the committee and to the staff for making it possible for me to appear today, which is later than the original schedule. This was very helpful. Secondly, I want to acknowledge the aid of Mr. I. G. Bowen, who is head of the physics department of the Lovelace Foundation in Albuquerque, whose knowledge and computational skill contributed to the analytical work that was incorporated in the prepared statement.

Thirdly, the work in blast biology with which I have been associated since 1952 has been sponsored mostly but not entirely by the Atomic Energy Commission under contract with the Division of Biology and Medicine.

Fourthly, I welcome the opportunity to talk about biological blast effects which certainly comprise one of the major early weapon effects responsible for hazard to man.

Fifthly, with regard to formalities, you have already mentioned the biography that was available for the record and I have furnished a prepared statement and wish to say that that is also for the record, if this is your pleasure.

Representative HOLIFIELD. It will be accepted in its entirety for the record.

(The statement referred to follows:)

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BIOLOGICAL BLAST EFFECTS

Remarks by
Clayton S. White, M.D.

Lovelace Foundation for Medical Education and Research
Albuquerque, New Mexico
June, 1959

Introduction

This presentation, though generally concerned with biological effects of airborne blast phenomena, will be limited to deal briefly with three main topics. First, the scope and nature of the several blast hazards will be delineated. Secondly, tentative criteria for threshold damage to humans will be set forth. Thirdly, these criteria will be related to nuclear weapons in terms of ground ranges and areas involved for 1 MT and 10 MT surface detonations, and to allow appreciation of the relative importance of blast with other effects, appropriate values for ionizing and thermal radiation will be noted.

Scope and Nature of Blast Hazards

General

Blast injury to a biological target, including man, depends primarily upon (a) the pressure pulse that emanates from an explosion in soil, water or air, (b) the mass movement of material surrounding the explosion which, in the case of air detonations, involves blast winds that accompany the pressure variations, and (c) the consequences of the interaction of these phenomena with the target and its immediate environment. All of these factors vary in magnitude and duration as dictated by a variety of circumstances among which are type and weight of explosive and range from the detonation.

Scope

For the purposes of discussion it is helpful to distinguish four categories of air blast damage to biologic media defined as follows (1, 2):

1. Primary blast effects include injuries caused by variations in environmental pressure which follow an explosion due both to the primary pulse and its reflections from structures or objects

near the biological target. These pressure variations are customarily measured in pounds per square inch (psi) either above or below the pressure existing prior to the detonation.

Biologic damage depends upon a variety of factors, including the rate, character and magnitude of the pressure rise and fall and the duration of the several segments of the pressure pulse.

2. Secondary blast injuries are those which follow the impact of penetrating and nonpenetrating missiles energized by blast winds.

   Important in "fixing" the hazard to animals and man are missile velocity, mass, size, shape, composition, and density, along with the specific regions and tissues of the body involved in the traumatic experience (3, 4, 5, 6).

3. Tertiary blast effects incorporate damage which is a consequence of physical displacement of the biologic target by blast shock and winds.

   The seriousness of the problem depends upon the magnitude of the accelerative "load" imposed on the total organism and its several parts, the decelerative experience — particularly when violent impacts with solid surfaces are involved — and the portions and areas of the body concerned. Thus, the time-history of displacement both during acceleration and deceleration are important. However, a less precise parameter — velocity at impact — is actually quite useful and has the virtue of simplicity.

4. Miscellaneous effects of blast, biologically, can involve exposure to ground shock; dust, whether arising from the earth's surface or the walls of inhabited structures; and temperature phenomena — other than those related to thermal radiation per se — such as compression and aerodynamic heating, contact with hot dust and debris and conflagration heat from blast-produced fires.

Nature of Blast Injuries

Since blast injuries and related problems have been extensively studied and described (1-4, 7-55) and applicability of the data to long duration overpressures and to displacement and missile hazards directly related with nuclear blast has to some extent been explored (1-4, 44-55), only a cursory summary of pathology will be detailed here.

Primary Blast

With regard to pressure-related phenomena, as a general rule, one can say damage is most marked in those regions wherein there exists the greatest variation in tissue density and, particularly, in the air-containing organs of the body. A corollary of these facts is that the air-containing organs, their nearby tissues and the junction of the ribs and soft tissues are sensitive indicators of blast damage; e.g., the eardrum, the sinuses and lung.

The most dangerous lesion, usually associated with fatality within a few minutes, involves lung damage resulting in "air" bubbles reaching the general circulation, including the vessels of the heart and brain. Also, suffocation from lung hemorrhage and edema with heart failure from lack of oxygen and high concentrations of carbon dioxide can occur early. Bruising and bleeding of the lung, if untreated, can result in serious pneumonic infections in humans. Too, unless cases with lung hemorrhage can be kept at rest, recurrence of bleeding is a frequent and quite serious complication. Bruising of the heart, the liver, spleen and abdominal organs, with areas of hemorrhage and sometimes rupture of the hollow viscera occur. Late complications from perforation peritonitis, pneumonia with lung abscess and areas of degeneration in the central nervous system require careful and prolonged care.

One new (57) lesion, discovered by Richmond recently, involves fracture of the thin bones separating the paranasal sinuses from the orbit. The finding was observed during shock tube exposure of animals to pressure conditions realistically simulating nuclear blast.

Missiles

Missiles which penetrate into major body cavities and damage critical organs, such as the heart, liver, spleen, other abdominal organs, the eyes

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and brain, are similar to the ballistic problems associated with war casualties (5, 6, 58-64). Many of these require early surgery to avoid fatalities, appropriate care for fractures and prolonged treatment to handle infections of major body cavities and deep lacerations.

Nonpenetrating missiles impacted against the chest can produce bilateral lung lesions very similar to those of primary blast with early fatality (64). Skull fracture, concussion, rupture and hemorrhage of the liver and spleen, and skeletal fracture can be very dangerous as can crushing injuries from heavy masses of masonry and other building materials (65-73).

Displacement

Damage from displacement can be of two general types. One type involves differential displacement of different portions of the body — loss of a hand or limb, for example. The other type occurs from total displacement of the entire organism with the decelerative experience being the most hazardous. The trauma which occurs can be similar to automobile and aircraft accidents and, in type and required treatment, poses only a few problems of an unusual nature. However, the hazards of violent impact are of considerable importance in the case of nuclear explosions because of the great range and long duration of the blast winds (1, 49-53, 65, 67-79).

Miscellaneous Effects

The nature of damage from ground shock concerns trauma from displacement and impact with heavy objects as has been noted above.

Sufficiently high concentrations of dust under certain circumstances has proved fatal to man simply through deposit in, and obstruction of, the small airways of the lung (80). The danger depends upon time of exposure and the concentration of appropriately sized dust particles. Studies inside blast protective shelters at the Nevada Test Site indicate there need be no serious hazard to occupants providing the inside walls of structures are not finished with dust-producing materials (54).

Thermal problems can involve burns from other than thermal radiation, but these qualitatively are similar to the latter and others appearing before the Committee will deal with the injuries involving exposure to heat.

Combined Effects

In practice it is not the rule to observe primary, secondary or tertiary blast effects alone. Indeed, in a nuclear explosion these will be seen in all possible relationships, plus damage from ionizing and thermal radiation. It is instructive, however, to call attention to the Texas City Disaster of 16 and 17 April 1947, which has been well documented both from the physical (81) and medical points of view (39-42).

Figures 1 and 2 show missile damage to a grain elevator and oil storage tanks (81). Figure 3 depicts the inside of an industrial installation after the explosion, and gives some suggestion of the hazardous debris created by the blast (81). Figure 4 shows one type of injury from glass to an engineer sitting at a desk with his right side turned toward a window a few feet away (39). This man was blown under a table, was completely "blinded" by flying glass, and was dazed but not unconscious. He noted chest pain, coughed blood intermittently for a week and suffered the following injuries: penetrating wound of the right eye with prolapse requiring evisceration; multiple lacerations of the right side of the face with severance of the facial nerve and parotid duct; lacerations of the neck, eyelids, left deltoid region and both lower extremities; perforation of the right eardrum and blast injury to the lung (39).

Two other cases are quoted from the report of Drs. Virginia and T.G. Blocker (39).

> "Case V. N.B., a colored female, aged thirty-seven, was standing out in the open near the Seatrain with her left side turned toward the ship. She felt the blast and saw debris flying through the air in all directions before she was knocked unconscious by a flying missile. When she 'came to', she was in water up to her waist and part of her clothes had been blown off. The patient was approximately two months pregnant at the time, and within an hour had an inevitable abortion without complication. Injuries sustained were (1) severe laceration of the left leg; (2) lacerations of the scalp; (3) mild head injury; (4) perforation of the left eardrum; (5) spontaneous abortion; and (6) minor abrasions and contusions.
>
> "Case VII. S.R., a colored male, aged thirty-nine, had just come

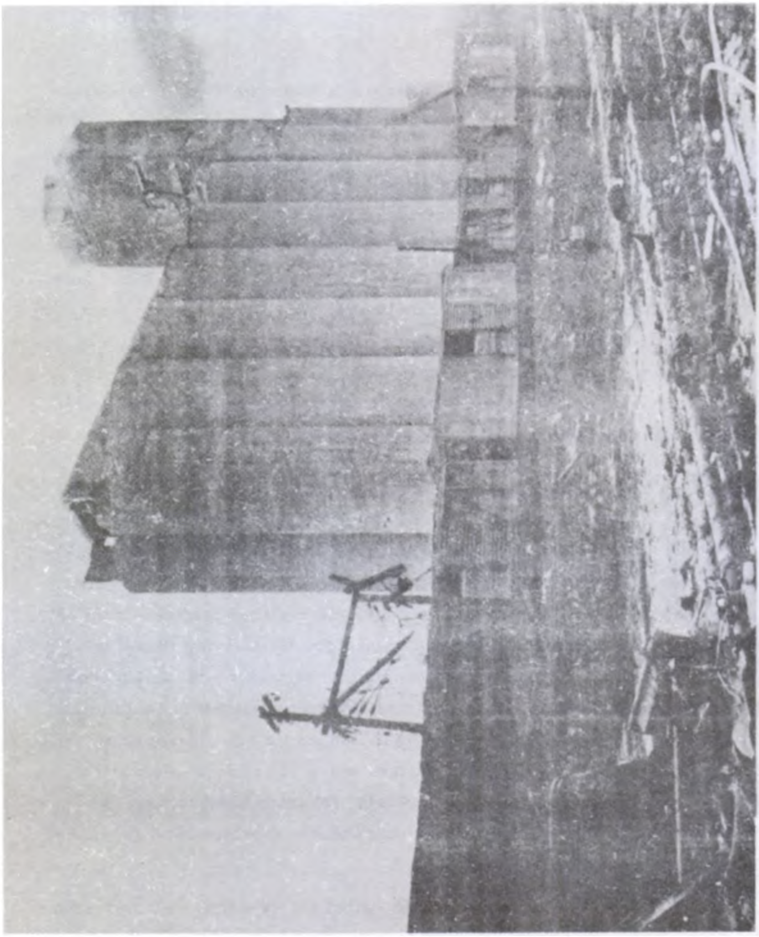

Figure 1. Missile and other blast damage to a grain elevator located approximately 600-900 ft from the explosions at Texas City. After Armistead (81).

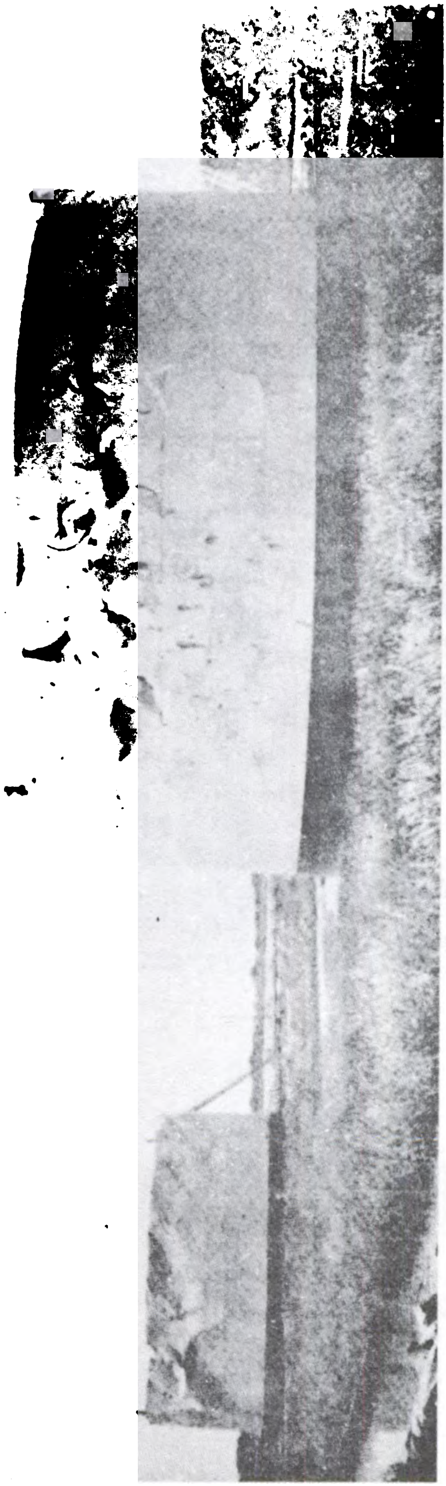

Figure 2. Missile and other blast damage to liquid storage tanks located about 3200 ft from one of the Texas City explosions. After Armistead (81).

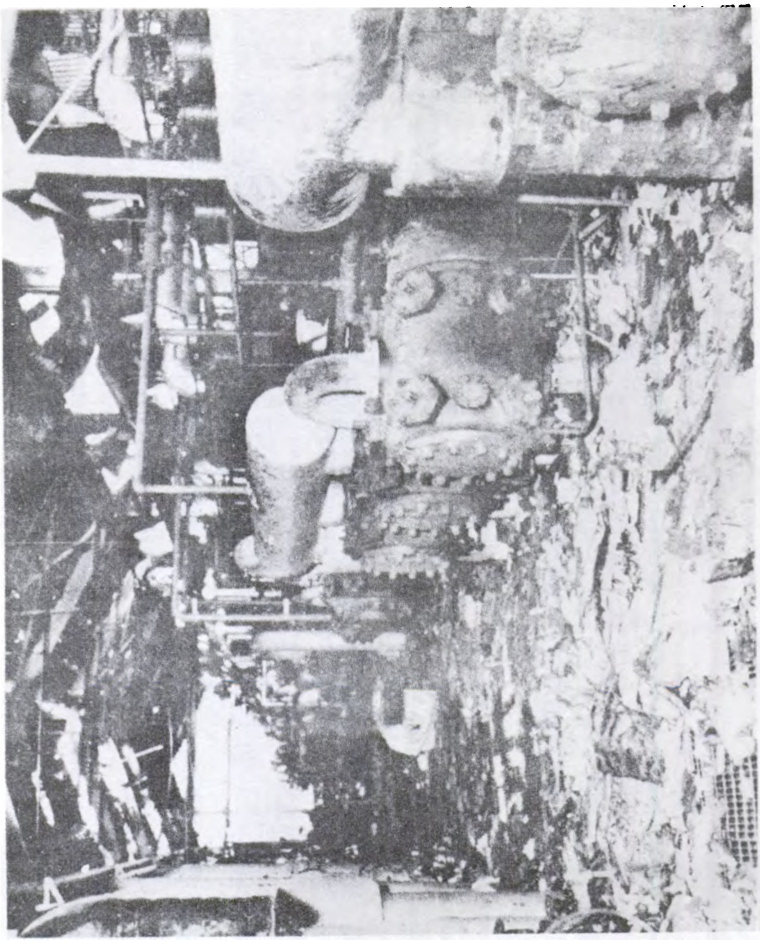

Figure 3. Missile and other blast damage to the compressor room of a chemical plant located about 2100 ft from one of the Texas City explosions. After Armistead (81).

Figure 4. Multiple lacerations of the face, head and neck of an individual located in an office with his right side turned toward a window. Approximate distance was 750 ft from one of the Texas City explosions. After Armistead (81) and Blocker and Blocker (39).

from loading flour on the High Flyer and was standing at the end of Pier O facing the burning ship. When the explosion occurred, he was thrown upward so high that he could see over Warehouse O; he was then blown laterally into the water near the Seatrain installation. He did not lose consciousness and was able to swim to land. Most of his clothes were blown off. Injuries sustained were (1) perforation of both eardrums; (2) severe scalp lacerations; (3) severe laceration of left upper arm with extensive infection; (4) left ulnar paralysis; and (5) laceration of right foot."

Figure 5 summarizes various types of injuries involved in the Texas City experience in which about 560 persons were killed or missing, 800 cases hospitalized and between 3,000 and 4,000 other less serious casualties occurred (39). The disaster illustrates very well the catastrophic character and nature of blast injuries and, if multiplied several fold, illustrates many of the biomedical consequences of large scale nuclear blast delivered to an unprotected urban or suburban area.

Tentative Criteria for Threshold Damage

A few selected quantitative data regarding the environmental conditions which define gross biological hazards will now be noted as background for fixing tentative threshold criteria for blast damage to humans. The objective is to estimate conditions likely to be at, or near, those which will just cause casualties, with a casualty defined simply as a person sufficiently injured to be unable to care for himself and thus become a burden to someone else. Information relevant to the primary, secondary, and tertiary problems will be set forth separately below.

Primary Effects

In general, it can be said that (a) mammalian material tolerates slowly rising overpressures much better than those developing almost instantaneously, and (b) overpressures of long duration are likely to be more damaging than pressure pulses of short duration.

Fisher, Krohn and Zuckerman (37, 38) in an excellent study at Oxford University, using high explosives and pressure pulses from 1 to 3 msec in

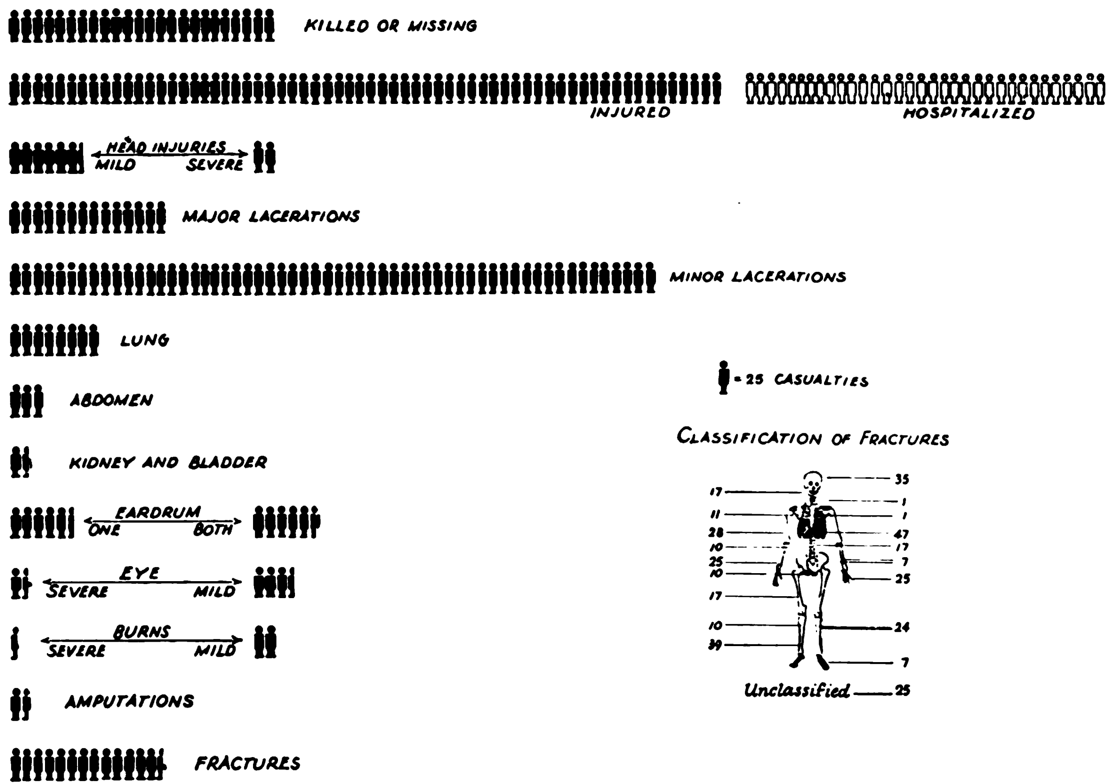

Figure 5. Comparison of the types of damages suffered by the injured at the Texas City Disaster. After Blocker and Blocker (39).

duration, have shown that the overpressures required to fatally injure 50 per cent (P_{50}) of mice, guinea pigs, rabbits, monkeys and goats were near 27, 32, 55, 100 and 200 psi, respectively. The figures could be related to the weight of the animals by the equation

$$P_{50} = 0.24\, W^{2/3} + 23.7$$

where

P_{50} = local static overpressure in psi
W = body weight in gms

The authors solved this equation for the 60 and 80 kgm man and predicted human tolerance to "short"-duration, high explosive generated overpressures would be 390 and 470 psi for 50 percent mortality, respectively. The same authors from field studies in bombed cities in England noted 12 human exposures for which the estimated overpressures ranged from 170 to 500-600 psi. There was one fatality related with 450 psi. Ten individuals survived from 170-450 psi and the other was not killed at between 500-600 psi.

These estimates of human tolerance did not contradict the observations of Desaga in Germany (9) who noted two deaths among 13 men exposed to high explosive bombs. The estimated maximal overpressure was 235 psi which resulted from an incident pressure of 58 psi reflecting from the corner walls of an open-topped, concrete, gun emplacement where the men were located. Desaga (9) further noted that man's tolerance to high explosive blast was similar to that of the large dog for which he noted just fatal conditions as follows:

Table 1

"Fast"-rising "Short"-duration Overpressures Required for Near 100 Per Cent Mortality in Dogs

Max Static Overpressure psi	Overpressure Duration msec
216	1.6
218	1.6
125	4.1
85	8.6
79	10.3
76	11.8

Clemedson (24) using mice in a shock tube study, confirmed the effect of duration on mortality, which data were also consistent with the opinions of Hooker who worked many years earlier in the United States (10).

Observations at the Nevada Test Site in 1953 revealed rather severe though non-fatal injuries to dogs exposed to nuclear-produced pressure pulses in open blast protective shelters at maximal overpressure between 12 and 25 psi, but enduring for from 500 to almost 800 msec. Too, there were findings indicating that the rate of pressure rise was of importance.

At the time, the Nevada experience seemed inconsistent with the earlier high explosive blast results, but it is now known from subsequent work in the field (1, 2, 49, 50) and in the laboratory (2, 55, 56) that studies of the effects of long duration overpressures simply extend the high explosive data. However, to date, the gap between the short duration high explosive work and the long duration field and shock tube investigations has not been filled, though appropriate experiments are now under way in Albuquerque.

The most recent experiments involving overpressures ranging from 80 to much over 1,000 msec in duration (56, 82) were carried out in a shock tube with four species of animals and represent the best data available for estimating human tolerance to long duration overpressures. Animals were exposed in cages bolted to a metal plate closing the end of the shock tube

and hence the incident and the reflected overpressures were applied almost simultaneously. To show the incident and reflected pressures associated with 1, 50 and 99 per cent mortality, Table 2 was prepared.

Table 2

Shock Tube Mortality Data for "Fast"-rising Long Duration Overpressures When Incident and Reflected Pressures Are Applied Almost Simultaneously

Animal Species	Overpressure in psi for indicated mortality					
	1%		50%		99%	
	Incident	Reflected	Incident	Reflected	Incident	Reflected
Mouse	7	20	11	29.8 ± 1.1	15	44
Rabbit	9	25	12	33.4 ± 1.2	15	44
Guinea pig	10	28	13	36.7 ± 0.7	17	48
Rat	10	28	14	38.7 ± 0.6	18	53
Man*		20-35		40-50		55-65

*Tentative estimate. Data AEC Project, Lovelace Foundation, Albuquerque, New Mexico.

The reader will note that Table 2 contains a tentative estimate of human tolerance which applies only to "fast"-rising, "long" duration pressure pulses. Too, it is important to understand that the pressures estimated for beginning mortality — 25-35 psi — can arise in two ways. First, in case an individual were close to a reflecting surface an incident pressure ranging from about 8 to 12 psi can reflect to 25-35 psi. In such a case the maximal pressure of 25-35 psi is applied almost instantaneously.

Secondly, an individual in the open or in a large building could be exposed to an incident pressure near 25-35 psi and in such a case a maximal pressure of this value would also be applied almost instantaneously. This point is emphasized because the pressures usually quoted in weapons effects manuals applies to incident, "free-field" pressures. It is necessary to specify tolerance in terms of the maximal, fast-rising pressure and to know that this can involve (a) an incident pressure which is maximal, or (b) a much lower incident pres-

sure which reflects to the maximal pressure specified. In terms of range from a nuclear detonation this distinction can involve a considerable variation in distance.

In passing, this point can be emphasized further by noting that if the cage of the guinea pig, for example, is mounted 1 ft from, instead of against the reflecting plate of the shock tube, the maximal or reflected pressure which is fatal to 50 per cent of the animals is quite different (56); e.g., about 58 compared with 37 psi maximal (reflected) overpressure. In the case of the higher tolerance the animal was first exposed to the incident pressure and about 1.4 msec later to the reflected or max pressure. Table 3 summarizes the situation for emphasis.

Table 3

Comparison of the Incident and Reflected Long-Duration Overpressures Fatal to 50 Per Cent of Guinea Pigs Exposed in a Shock Tube Against and 1 Foot from a Reflecting Surface

Location of cage	Overpressure in psi for 50 per cent mortality: incident	Overpressure in psi for 50 per cent mortality: reflected	Time interval in msec between incident and reflected pressure
Against end-plate	13	36.7 ± 0.7	Essentially none
1 ft from end-plate	18	57.1 ± 1.1	1.36

With regard to estimating a threshold for human damage to long-duration overpressure based on lung damage, it can be said that slight lung hemorrhage has been noted in mice, rabbits, rats and guinea pigs exposed in a shock tube against a reflecting surface to an incident overpressure of about 6 psi which reflected to near 15 psi. Consistent with this, an incident pressure of approximately 8 psi is known to have produced lung hemorrhage in a dog exposed in front of a reflecting surface to full-scale nuclear blast (53).

Thus, on the basis of the few animal data available on sharp-rising, long-duration pressure pulses, it is felt that human lung damage will occur in minimal form under circumstances which involve (a) an "open" exposure to 15 psi incident, or (b) exposure to 6 psi incident in a location where reflections to 15 psi max could occur almost immediately after arrival of the incident overpressure.

In case one desires to use the response of the more sensitive eardrum as a criteria in estimating the tolerance of man to blast, there are also uncertainties because the response of the human tympanic membrane to blast-produced overpressure is not known at all precisely. However, the classical study of Zalewski in 1906 (83) is helpful. Using human cadavers, this investigator applied slowly increasing pressures to the external auditory meatus until rupture of the eardrum occurred. Data are summarized in Table 4.

Table 4

Pressures Required to Rupture the Eardrums of Human Cadavers and Dogs when Pressure was Applied Within 24 Hours After Death (83)

Species Studied	Number of cases	Age group in years	Pressures required to rupture tympanic membranes in psi		
			minimum	maximum	mean
Human	19	1 - 10	20.9	43.2	33.1
	15	11 - 20	6.0	44.1	25.5
	15	21 - 30	15.3	29.6	20.5
	17	31 - 40	6.4	35.4	23.2
	11	41 - 50	16.8	31.5	20.7
	12	51 - 60	13.5	38.3	21.0
	14	61 - 70	5.4	31.5	18.8
	8	Above 70	16.2	26.5	20.7
Total	111	Average	5.4	44.1	22.9
Dogs	10	Not stated	9.1	22.8	14.9

The average pressure required to rupture the human eardrum varied with age from about 33 psi for the first decade of life to near 20 psi for the older age groups. However, the lowest and highest pressures for rupture were 5.5 and 44.1 psi, respectively. Dogs (age not stated) similarly studied by Zalewski revealed pressures for rupture ranging from about 9 to 23 psi with a mean of 15 psi. Exposure of young dogs to nuclear blast at the Nevada Proving Grounds (1, 50) indicated that the maximal pressures for rupture of the eardrum ranged from 4.1 to 85.8, with 31.2 psi being the statistically determined pressure required for 50 per cent failure of the tympanic membrane (50). The highest overpressure without rupture was noted to be 66.6 psi.

Apparently the blast data for young dogs are fairly close to the laboratory results obtained on human material. Too, the studies of Zuckerman (43) noting human field data in bombed British cities are reasonably consistent with the material presented previously.

On a tentative basis, therefore, it seems reasonable to believe that human eardrum failure begins at near 5 psi maximal which can be either an incident or reflected overpressure. In case of the latter, about 2.5 psi is close to the incident pressure which will reflect to 5 psi under appropriate conditions.

Human response to slowly rising overpressures of both short and long duration is not known. However, it has been demonstrated that dogs are much more tolerant to long-duration pressures rising to a maximum in from 20 to 150 msec (48) than they are to sharp-rising pulses. Eardrum failure, damage to the sinus membranes and fracture of the thin orbital bones do occur, though lung damage is markedly minimized for the slower rising overpressures. Further details need not be given here since the present objectives are directed to setting thresholds involving the minimal overpressure which is likely to cause human casualties.

Secondary Effects

The physical and biological factors that determine the seriousness of human injury from objects striking the surface of the body — whether or not they penetrate skin tissues and bone — are complex indeed. Ignoring most of these, and for the sake of brevity, the missile problem will be limited and simplified here by using only impact velocity and missile mass to illustrate the just threshold conditions for penetration into a major body cavity of a dog and for nonpenetrative fracture of the human skull.

Table 5 gives the data of Bowen, et al. (4) obtained by firing irregular glass missiles against the abdominal wall of dogs, and in terms of missile mass and impact velocity, defines conditions for expecting glass missiles to pierce the body wall and enter the abdominal cavity 1, 50 and 99 per cent of the time.

Table 5

The Velocity-Mass-Probability Relationships Required for Small Window Glass Fragments to Traverse the Abdominal Wall and Reach the Peritoneal Cavity of Dogs*

Mass of glass fragment gms	Impact velocities in ft/sec for indicated probabilities of penetration in per cent		
	1%	50%	99%
0.05	320	570	1000
0.1	235	410	730
0.5	160	275	485
1.0	140	245	430
10.0	115	180	335

*Data from Bowen, et al., AECU-3350

The reader will note that a 10 gm glass fragment, having a velocity of 115 ft/sec has only a 1 per cent probability of traversing the abdominal wall of a dog. Since clothing will degrade the velocity of small missiles moving relatively slowly, and because of the less serious nature of skin and tissue lacerations, an impact velocity of 115 ft/sec for a 10 gm glass fragment has been arbitrarily chosen as the threshold for human casualties from glass and other frangible materials. Such a decision may well have to be modified later, since a quantitative study of eye injury from glass and other small irregular missiles has not yet been done. However, the 10 gm-115 ft/sec criteria is strengthened somewhat by the data of Journee (5) who noted that spherical bullets weighing 8.5 gm only produced a contusion of the skin when fired at human cadavers at velocities up to 150 ft/sec, whereas a velocity of 128 ft/sec for 6 to 12 mm caliber rifle bullets was set as the lower limit at which penetrating wounds begin in man (5).

The realistic nature of the masses and velocities of glass fragments noted in Table 5 is established by the figures in Table 6 which details the masses and velocities for glass, stone and irregular steel objects empirically observed at stations located from the 1.9 to 17.3 psi lines during full-scale nuclear explosions at the Nevada Test Site. Unfortunately, to date, no full-scale missile experiments have been carried out to determine the expected missile environment inside a variety of industrial plants, office buildings

Table 6

Relation Between Overpressure and Missile Parameters

Max pressure psi	Type of missile	Velocity ft/sec geometric mean	Velocity ft/sec range	Mass, gms geometric mean	Mass, gms range	Max missile density No/sq ft
1.9	Window glass	108	50-178	1.45	0.03-10	0.4
3.8	Window glass	168	60-310	0.58	0.01-10	159
5.0	Window glass	170	50-400	0.13	0.002-140	388
8.5	Natural stones	275	167-413	0.23	0.038-22.2	35
15.0	Natural stones	692	379-1100	0.50	0.043-8.82	4.7
17.3	Natural stones	432	300-843	0.21	0.010-13.4	99.1
17.3	Irregular steel objects	240	195-301	34.5	9.0 - 86.0	3.6

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and other structures much larger than the "typical" brick and wooden frame houses to which past studies have been limited.

Objects striking the human head may cause skull fracture and concussion, both potentially dangerous experiences. Fortunately, quantitative investigations by Gurdjian, et al. (70), using human material, are available to support an estimate of the skull-fracture hazard. Using the data of these authors and adopting a missile of 10 lbs, which is near the average weight of the adult, human head, Table 7 was computed to state the impact velocities that can be associated with skull fracture. The table shows considerable variation in velocities required for fracture; e.g., the minimum impact velocity associated with fracture was near 15 ft/sec, while the maximal without fracture was computed to be 23.1 ft/sec.

Table 7

Average Minimal Impact Velocities From a 10 lb. Missile Expected to Cause Skull Fracture and Maximal Velocity Without Fracture

Region of blow	Impact velocities expected to fracture the human skull* ft/sec	mph
Posterior midline	16.6	11.3
Frontal midline	17.4	11.8
Above ear	18.2	12.4
Top midline	19.4	13.2
Maximal without fracture	23.1	15.7
Minimal with fracture	14.6	9.9

*Computed from the data of Gurdjian, et al. (70)

Although damage to the thorax and lungs from the impact of 0.4 and 0.8 lb. nonpenetrating missiles have been studied, information for heavier and lighter objects is lacking (64, 82). Also unavailable, are quantitative figures for missile impact velocities near and over the regions of the liver and spleen that will rupture these friable organs and produce hemorrhage often severe enough to require early surgery if fatality is to be avoided.

Under such circumstances, 10 ft/sec has been adopted tentatively as the impact velocity for a 10 lb nonpenetrating missile, below which the number of human injuries will approach a minimum.

Tertiary Effects

To deal simply with the hazards of displacement from blast-produced winds, it has been assumed that significant human injury will occur mostly during decelerative impact with solid objects having a mass much greater than that of man. Data from four sources has been selected as guides in estimating threshold conditions for injury.

First, it is useful to note an animal study involving decelerative impact which reported the impact velocities associated with 50 per cent mortality in mice, rats, guinea pigs, and rabbits to be 38, 44, 31 and 31 ft/sec, respectively. Extrapolation of these figures to man predicts that on the average an impact velocity of 27 ft/sec or 18 mph would be associated with death of half the individuals (82). These are interesting figures because National Safety Council reports on urban automobile accidents have associated a mortality of 40 per cent with automobile accidents at speeds of less than 20 mph and a 70 per cent fatality rate with speeds of less than 30 mph (69). Table 8 summarizes the above data.

Secondly, Black, et al. (76) dropped human cadavers feet first with knees locked onto a hard surface from heights of 1, 2, 3, 4 and 6 feet and concluded that the threshold for fracture of the heel, foot and ankle bones lay between impact velocities of 11 and 16 ft/sec. Draeger, et al. (79) using an impact table and human cadavers to study ankle and foot fracture, demonstrated an impact velocity of 12-13 ft/sec (8-9 mph) to be near the threshold for skeletal fracture of the lower extremities.

Thirdly, Gurdjian, et al. (70). by drops onto a solid surface, subjected heads of human cadavers to impact loading and defined conditions for experimental skull fracture. The findings have been summarized in Table 9 in terms of impact velocity. Fracture was produced at a minimal impact velocity of 13.5 ft/sec (9.2 mph), while the maximal velocity without occurrence of fracture was 22.8 ft/sec (15.5 mph). These findings are fairly consistent with British work done during the Second World War (76, 78).

Table 8

Average Velocities of Impact Against a Hard Surface Associated with 50 Per Cent Mortality of the Indicated Species of Animals with Extrapolation to Man*

Species of Animal	Average animal mass gms	Average impact velocity for 50 per cent mortality ft/sec	mph	Equivalent height of fall (approx.) ft
Mouse	19	38	26	22
Rat	180	44	30	30
Guinea pig	650	31	21	15
Rabbit	2,600	31	21	15
Man (computed)	72,574 (160 lbs)	27	18	11

National Safety Council release on urban automobile accidents shows 40 and 70 per cent of fatalities were associated respectively with speeds of or less than 20 and 30 mph. - Quoted from De Haven.

*Data AEC Project, Lovelace Foundation, Albuquerque, N.M.

Table 9

The Ranges of Impact Velocities Associated with Experimental Fracture of the Human Skull

Range impact velocities ft/sec	Approx. velocity in mph	Approx. height of fall in.	Number of subjects	Fractures in per cent
13.5-14.9	9.5	37	9	19
15-16.9	10.9	48	10	22
17-18.9	12.2	61	12	26
19-20.9	13.6	75	11	24
21-22.9	15.0	91	4	9
Total			46	100

Minimum velocity with fracture - 13.5 ft/sec (9.2 mph)
Maximum velocity with fracture - 22.8 ft/sec (15.5 mph)
Maximum velocity without fracture - unstated.

Fourthly, from the findings of Ruff (84), it is possible to deduce a velocity of about 8 ft/sec (6 mph) as likely to produce spinal fracture assuming impact with a solid surface in the sitting position.

The above data encourages one to adopt an impact velocity of 10 ft/sec as a tentative threshold criteria for human damage from abrupt decelerative impact following displacement by blast-produced winds. Though arbitrarily chosen, the 10 ft/sec (6.8 mph) figure is quite likely low enough to avoid any significant number of casualties and if serious injuries occur, they are likely to be few indeed.

Empirical work by Taborelli, et al. (51, 52) in the 1957 Nevada Test Series, using 160 lb anthropometric dummies exposed at stations where measured overpressures were 5.3 and 6.9 psi, demonstrated the displacement possible to humans from nuclear blast. Table 10 summarizes the findings.

Table 10

Blast Displacement of 160 Lb Anthropometric Dummies

Max pressure psi	Max Q psi	Initial dummy position	Max horizontal velocity ft/sec	Time to max velocity sec	Displacement in ft
5.3	1.8	Standing	21.4	0.5	21.9 downwind
		Prone	zero	-	None
6.9	15.4	Standing	not known	not known	256 downwind 44 to right
		Prone	not known	not known	124 downwind 20 to right

Even at 5 psi the maximal velocity attained in 0.5 sec by the dummy was a little over 21.4 ft/sec, which speed is well above those required to fracture the skull and lower extremities. Though the displacement velocity at 6.9 psi was not obtained in the Nevada studies, the total displacement of 124 and 256 ft for the prone and standing dummies, respectively, demonstrates the unequivocal displacement hazard which can occur following nuclear explosions.

Miscellaneous Effects

No attempt has been made to deal with the threshold for human casualties as a consequence of miscellaneous blast effects. Those, however, who wish to explore the dangers from dust are referred to the publication of Desaga (80).

Summary

The tentative criteria described above for primary, secondary, and tertiary blast effects representing those conditions thought to be near the human casualty threshold are summarized in Table 11. It is the current opinion of the writer that the data in Table 11 represent best estimates for conditions at which human casualties will approach a minimum; e.g., some individuals situated where the indicated overpressures, missile and displacement velocities exist will escape damage because of fortunate local geometry; many persons will be injured, but only to the extent that they can care for themselves; others will become casualties in that they require care from their associates, but these will be relatively few indeed.

Table 11

Threshold Criteria Estimated to be Near Conditions at Which Casualties Will Approach a Minimum or be Absent

Blast Effect		Criteria adopted as indicated
Primary	Lung damage	15 psi incident and maximal overpressure 6 psi incident reflecting to 15 psi maximal
	Eardrum rupture	5 psi incident and maximal overpressure 2.5 psi incident reflecting to 5 psi maximal
Secondary	Penetration into abdomen	115 ft/sec for a 10 gm glass missile
	Nonpenetrative skull fracture	10 ft/sec for a 10 lb masonry missile
Tertiary	Skull fracture from impact	10 ft/sec for 160 lb man

Relation of Blast Criteria to Nuclear Explosions*

An attempt will now be made to relate the arbitrarily chosen and tentative criteria for threshold biological blast damage to nuclear war. Specifically, the ranges and areas involved for potential damage to man will be presented only for surface nuclear detonations of 1 and 10 MT explosive yields.

To aid initial orientation, Figure 6 was prepared, using the data of Glasstone for surface bursts at sea level (85). The figure shows iso-pressure lines from ~~1~~ 2,5 to 100 psi defining the expected range-yield relationships for detonations of megaton yield. The overpressures represent "free-field" phenomena — overpressures which would occur over open terrain in the absence of buildings and other structures — and are maximal incident pressures measured side-on to the advancing pressure front.

Primary Blast Effects

Figure 6 contains iso-pressure lines for 2.5, 5, 6 and 15 psi which overpressures were noted in Table 11 to be related with the criteria adopted for primary blast effects. Table 12 notes these pressures and shows the ranges from ground zero and the areas covered for surface burst explosions of 1 and 10 MT.

With regard to the threshold of 5 psi maximal for beginning failure of the normal human eardrum, Table 12 shows that this effect can be expected out to ranges of 2.8 and 6.1 mi for 1 and 10 MT surface bursts, respectively, at which distance an incident and maximal "free-field" overpressure of 5 psi is predicted. The corresponding areas are 25 and 120 square miles.

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*The author wishes to acknowledge the helpful cooperation of Mr. I. G. Bowen, Head of the Physics Department, Lovelace Foundation, who contributed the analytical work required for formulating the tables and charts used in this section (86).

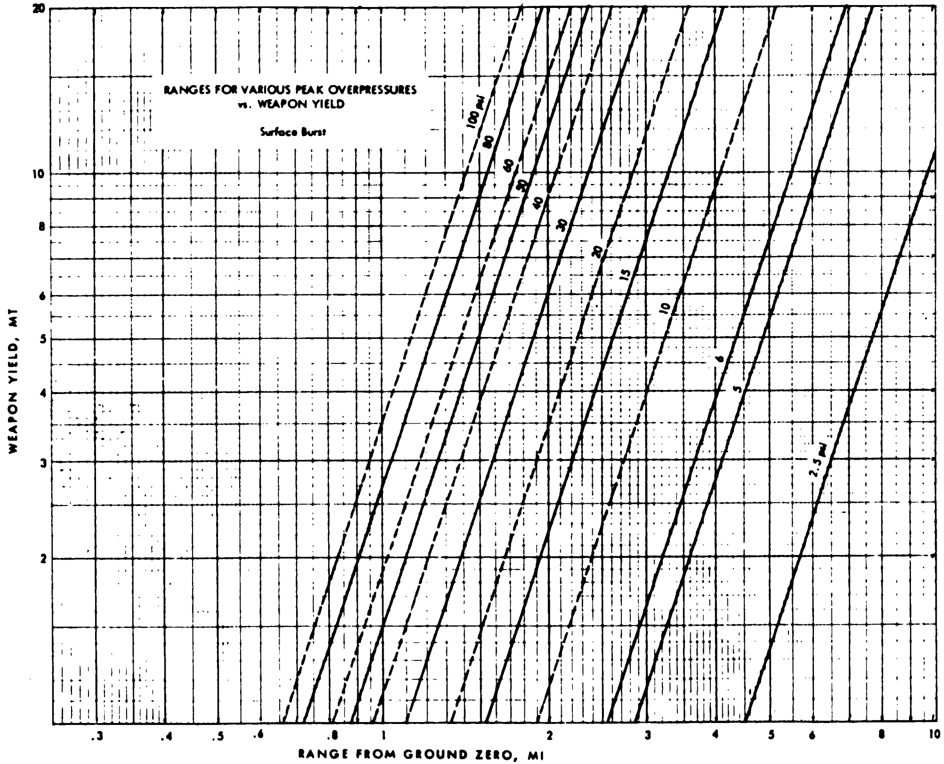

Figure 6. Ranges for various free-field incident overpressures for megaton explosions, surface burst at sea level. Data from The Effects of Nuclear Weapons (85).

Table 12

Ground Ranges and Areas for the Indicated Overpressures Arising from 1 and 10 MT Surface Bursts at Sea Level

Incident Overpressure, psi	Corresponding Range and Area			
	1 MT		10 MT	
	mi	sq mi	mi	sq mi
2.5	4.5	64	9.7	300
5.0	2.8	25	6.1	120
6.0	2.6	21	5.5	95
15.0	1.5	7.1	3.3	34

In case exposure of man close to a reflecting surface or in other situations where reflections of pressure to 5 psi maximal might occur, it is necessary to note the distances and areas for 2.5 psi incident overpressure, for the latter can and will reflect to 5 psi under appropriate conditions. Thus, the maximal range for rupture of the tympanic membrane can be 4.5 and 9.7 mi, involving areas of 64 and 300 sq mi for the 1 and 10 MT surface bursts, respectively.

Because rupture of the tympanic membrane can be regarded as a primary blast injury which is "acceptable" in an emergency, it is helpful to note the ranges and areas for the criteria adopted for lung damage. In a geometry of exposure conducive to producing sharp pressure reflection, Table 12 shows that human lung damage might occur out to 2.6 and 5.5 mi, covering areas of 21 and 95 sq mi for 1 and 10 MT weapon yields, respectively, which data apply to the range of the "free-field" 6 psi incident overpressure assuming reflections to 15 psi maximal. For circumstances wherein pressure reflections would be minimal, the ranges for a free field incident overpressure of 15 psi would apply; e.g., ranges and areas of 1.5 mi and 7.1 sq mi for the 1 MT and 3.3 mi and 34 sq mi for the 10 MT yields, respectively.

Secondary Effects

The situation for biologic damage from impact with either penetrating or nonpentrating missiles is not quite so clear-cut as is the case with damage from overpressure. One complicating circumstance arises from the fact that blast energized missiles, depending upon their mass, size and shape and the magnitude of the blast winds, gain velocity as a function of time, and during the phase of increasing velocity cover a finite distance. This statement means, among other things, that the velocity at impact is a function of the distance (and time) the missile travels before striking a biologic target. Thus, any attempt to assess the missile hazard briefly, forces an arbitrary decision as to the distance a target might be from the potential source of missiles; e.g., if one were 10 ft from a glass window, the missile velocity would be different than at 2, 5 or 20 ft.

For the present analysis, 10 ft of missile travel was arbitrarily selected and used by Bowen in computing the figures presented in Table 13, setting forth the overpressures, ranges and areas for the missile criteria adopted previously (see Table 11). For example, the overpressures at which a 10 gm glass missile would gain a velocity of 115 ft/sec in 10 ft of travel were calculated to be 2.2 psi for both the 1 and 10 MT surface bursts. The overpressures are of similar value for the two yields because the missile gains velocity very rapidly in the early phases of its displacement. Differences between the 1 and 10 MT yields only become apparent at distances of missile travel greater than 10 ft.

The 10 gm-115 ft/sec-10 ft criteria for the glass missile is met at ranges of 4.9 and 11 mi, covering 75 and 380 sq mi for 1 and 10 MT surface bursts, respectively.

Likewise, Table 13 shows the overpressures, ranges and areas for the 10 lb masonry missile to reach a velocity of 10 ft/sec in 10 ft of travel. For 1 and 10 MT yields the figures respectively are 2.4 and 2.1 psi, 4.6 and 11 mi, and 66 and 380 sq mi.

In addition, Table 13 shows data applicable to circumstances for which the 10 lb masonry missile was allowed to reach maximal velocity rather than

Table 13

Overpressure and the Respective Ranges and Areas
Computed for the Indicated Missile Velocities
Expected from a 1 and 10 MT Surface
Burst at Sea Level

	Incident overpressures, ranges and areas					
	1 MT			10 MT		
	psi	mi	sq mi	psi	mi	sq mi
10 gm glass fragment, 115 ft/sec in 10 ft:	2.2	4.9	75	2.2	11	380
10 lb masonry, 10 ft/sec in 10 ft:	2.4	4.6	66	2.1	11	380
10 ft/sec:	2.2*	4.9	75	1.5*	14	620

*Minimum overpressure where a velocity of 10 ft/sec is predicted. Corresponding displacements are: 1 MT - 26 ft
10 MT - 58 ft

the velocity over 10 ft of travel. It is instructive to note that winds from a 1 MT surface burst can energize a 10 lb masonry missile to a maximum velocity of 10 ft/sec over 26 ft of travel at a range of 4.9 mi from ground zero where an overpressure of 2.2 psi is expected. Area involved is computed to be 75 sq mi. For the 10 MT case, a velocity of 10 ft/sec over 58 ft of missile travel can occur at a minimum overpressure of 1.5 psi, reaching to 14 mi and covering an area of 620 sq miles.

Tertiary Effects

Dealing with the physical displacement of man involves treating man as a missile for computational purposes. As was the situation with the glass and masonry missiles, displacement velocity, among other things, is a function of time and distance. Calculations, for example, at 6 psi (Nevada altitude) for a yield of 10 MT indicate that a 160 lb object would reach a maximal velocity of 97 ft/sec (66 mph), at which time the distance of travel would be 330 ft. Because there are not very many circumstances in which a man might be thrown hundreds of feet without striking some object, data pre-

pared for the present study were limited to displacement distances of 1, 2, 5 and 10 ft.

Consistent with this, Table 14 shows the overpressures, ranges and corresponding areas at which a 160 lb human being would reach a velocity of 10 ft per second in 1, 2, 5 and 10 ft of travel. For 1 MT yields, the corresponding overpressures range from 4.3 to 2.1 psi for displacement distances of 1 and 10 ft, respectively; the corresponding range and areas are 3.1 and 5.1 mi and 30 and 82 sq mi. A 10 MT surface burst is similar overpressure-wise, being 4.3 and 1.8 psi for a velocity of 10 ft/sec over 1 and 10 ft displacements, respectively. However, the corresponding ranges and areas vary from 6.8 to 12 mi and 150 and 450 sq mi, respectively.

Minimum overpressures where a velocity of 10 ft/sec can be predicted for a 160 lb man, involving displacements of 28 and 55 ft at the time maximum velocity would be reached, are also given in Table 14. In these cases, ranges of 5.5 and 16 mi and areas of 95 and 800 sq mi can be involved for the smaller and larger yields, respectively.

Weapon-Threshold Criteria Summary

A summary of the interrelations between the several tentative criteria adopted to estimate the thresholds of human injury from blast phenomena in terms of ranges and areas involved is given in Figure 7 for 1 MT and in Figure 8 for the 10 MT surface bursts. To a great extent, of course, the two figures reflect the arbitrary choice of criteria, but each serves to show the ranges from ground zero at which primary, secondary and tertiary blast casualties will begin. Stated another way, one can say that inside the ranges shown for each effect, blast-related casualties will progressively increase in number.

In general, Figures 7 and 8 indicate a trend implying that the potential hazard from displacement is more significant than missile damage and that missile damage, in turn, is more important than primary blast injury. To be sure, conditions at the time of exposure will be critical, and no doubt entirely unpredictable for an uninformed and unprotected population under nuclear attack.

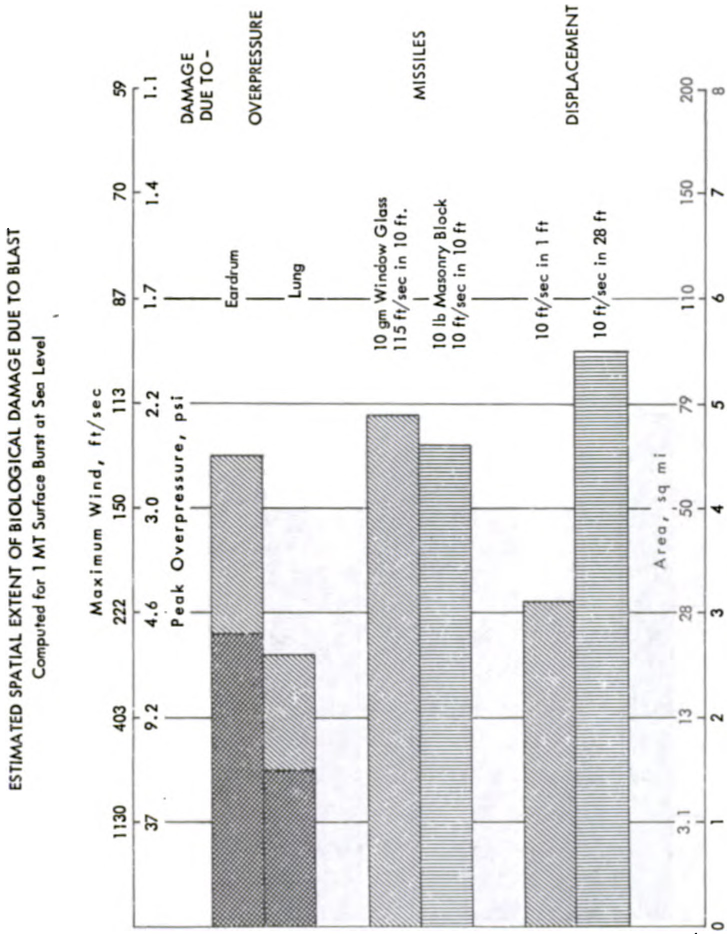

Figure 7. Approximate overpressures, ranges and areas for a 1 MT surface burst at sea level, corresponding to tentative criteria estimating thresholds of human injury from primary, secondary and tertiary blast effects. Data computed by Bowen (86).

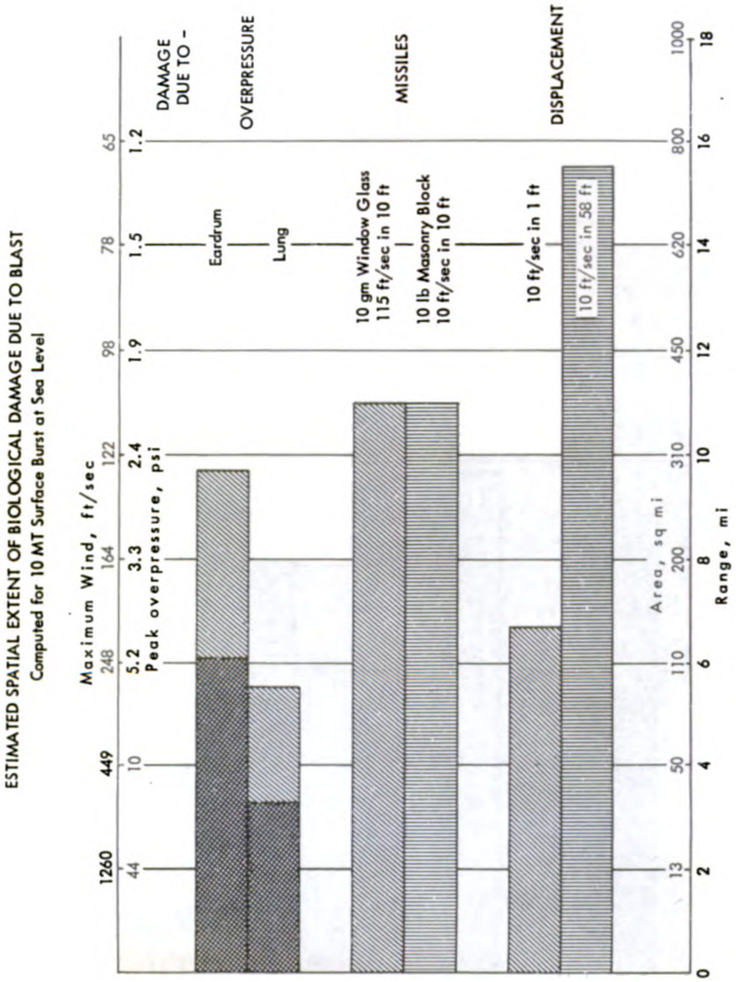

Figure 8. Approximate overpressures, ranges and areas for a 10 MT surface burst at sea level corresponding to tentative criteria estimating thresholds of human injury from primary, secondary and tertiary blast effects. Data computed by Bowen (86).

Table 14

Overpressures Computed for an Expected Displacement Velocity of 10 ft/sec for a 160 lb. Human Being Travelling the Indicated Distances. Ranges and Areas Computed for Surface Bursts at Sea Level

Displacement in ft corresponding to velocity of 10 ft/sec	Incident pressure and corresponding range and area					
	1 MT			10 MT		
	psi	mi	sq mi	psi	mi	sq mi
1	4.3	3.1	30	4.3	6.8	150
2	3.3	3.7	43	3.3	8.0	200
5	2.4	4.7	69	2.3	10	310
10	2.1	5.1	82	1.8	12	450
	1.9*	5.5	95	1.3*	16	800

*Minimum overpressure where velocity of 10 ft/sec is predicted.
Corresponding displacements are: 1 MT - 28 ft
10 MT - 58 ft (After Bowen (86))

With regard to this statement, it is clear that if one were to stand against a wall to avoid exposure to blast winds, displacement injury might not occur, but the hazard from pressure reflections would be increased. Likewise, avoiding contact with firm surfaces to minimize injury from overpressure markedly increases the dangers of displacement. In either case, there exists the missile hazard, and the data clearly indicate that much in the way of protection could be achieved by avoiding blast winds and missiles whether the latter are those impelled by the blast winds or fall due to gravity following the passage of the pressure pulse. In quantitative terms, protection from missiles and blast winds — which might be achieved using a simply constructed fallout shelter — might well reduce the range of serious blast hazards from a 10 MT surface burst from 16 mi (Table 14) to 3.3 mi (Table 12), a difference in area involving 800 minus 34 or 766 sq mi.

There can be no question of the worth of such measures to avoid blast

casualties, but an understanding of the feasibility of protection from nuclear weapons involves consideration of factors other than blast effects.

Relation of Blast to Other Effects

To gain some perspective with regard to the total problem of protection, Table 15 was prepared using data from Glasstone (85) and is presented in preliminary form to point out the need for assessing the relative importance of thermal and initial ionizing radiation compared with blast phenomena. Though the figures for thermal radiation shown are well above those ordinarily assigned for first and second degree burns of the skin at all overpressures associated with the blast criteria presented in Tables 12, 13 and 14 — as is summarized in Tables 16 and 17 — it is nevertheless true that the missile hazard is worse inside buildings than in the open. Germane to this remark, is the fact that thermal fluxes noted in Tables 15, 16 and 17 are those for "free-field" conditions and they will actually be much lower by some unknown amount inside structures; e.g., conditions which maximize the missile hazard, tend to minimize injuries from thermal radiation.

Also, the figures for prompt ionizing radiation are of importance. Interestingly enough, even up to overpressures of 15 psi used as one of the primary blast criteria, prompt radiation expected for the 10 MT case is only about 10 rem (see Tables 15 and 17). Since this is an easily acceptable radiation flux in an emergency, one can say that prompt radiation represents no hazard beyond the 15 psi range (3.3 mi — 34 sq mi).

For 1 MT surface bursts, however, prompt radiation at the 15 psi range (1.5 mi — 7.1 sq mi) is 500 rem, a dose to be avoided at all costs (see Tables 15 and 16). Thinking in this vein leads one to remark that protection against missiles and blast winds should be easy — a simple fallout shelter, for example. The use of such protection, however, will serve to degrade both thermal radiation and the "free-field" prompt radiation "doses" by whatever factor is appropriate to the shielding characteristics of the shelter. In any case, effective protection at overpressures of 15 psi is not difficult and only simple technical problems are involved in its achievement.

Table 15

Various Effects of Biological Interest as a Function of Range from Ground Zero for 1 and 10 MT Surface Burst at Sea Level

Range	1 MT				10 MT			
mi	P	IR	TR	V	P	IR	TR	V
.6	>100	>3000	880		>100	>3000	>1000	
.8	62	>3000	470		>100	>3000	>1000	
1.0	37	>3000	290		>100	>3000	>1000	
1.2	25	>3000	200	150	>100	>3000	>1000	
1.5	16	500	120	100	88	>3000	>1000	
2.0	9.2	40	65	60	44	850	650	
2.5	6.2	<10	40	39	27	120	400	
3.0	4.6	<10	27	28	18	23	270	110
4.0	3.0	<10	14	17	10	<10	140	65
5.0	2.2	<10	8.8	11	7.1	<10	88	46
6.0	1.7	<10	6.0	7.6	5.2	<10	60	32
8	1.1	<10	3.2	3.9	3.3	<10	32	20
10	<1	<10	2.0		2.4	<10	20	14
12	<1	<10	1.3		1.9	<10	13	11
15	<1	<10	.81		1.4	<10	8.1	7.5
20	<1	<10	.44		<1	<10	4.4	
25	<1	<10	.27		<1	<10	2.7	
30	<1	<10	.18		<1	<10	1.8	
35	<1	<10	.13		<1	<10	1.3	
40	<1	<10	<.1		<1	<10	<1	

P = peak overpressure in psi
IR = ionizing radiation, exposure dose in rem (initial)
TR = thermal radiation in cal/cm^2
V = velocity predicted for 160 lb man in a translation distance of 10 ft

Pressure and radiation data from Effects of Nuclear Weapons

This leaves one last major early effect of weapons — the residual radiation — to assess in relation to blast effects. This problem, along with firestorm, has been considered beyond the scope of this presentation, but a few general remarks are nonetheless indicated.

First, the greatest population density is likely to be within the range of those weapon-produced hazards developing in a matter of seconds and minutes after an explosion — blast, prompt ionizing and thermal radiation effects. Because of the large number of people involved, these "early" effects and the need for protection from them cannot be ignored. Further, the nature and unpredictability of the residual radiation, particularly that due to fallout and the high levels involved from the latter, makes evacuation an unattractive policy. Under such circumstances the levels of residual radiation to be expected at very close ranges from ground zero — like 1, 2, 5, 10, 15, 20 and 30 miles — should and must be estimated if planning for maximal protection is to be sensible and complete. There can be no doubt that this is a critical problem and one regarding which very little empirical data are available.

Even without introducing thinking regarding protection, the "very close in" residual radiation levels need to be known to aid understanding and estimating the "cost" of nuclear war to a nation whose population is practically "naked" and completely unprepared and unprotected for a full-scale nuclear attack.

Table 16

Comparative Weapons Effect Data
Applicable to Indicated Blast Criteria
for a 1 MT Surface Burst at Sea Level

Incident over-pressure psi	Range in mi	Initial ionizing radiation rem	Thermal radiation cal/cm^2	Blast criteria for primary, secondary and tertiary effects
1.9	5.5	<10	7.2	Displacement of man 160 lb 10 ft/sec in 28 ft
2.1	5.1	<10	8.4	Displacement of man 160 lb 10 ft/sec in 10 ft
2.2	4.9	<10	9.3	Missiles (glass) 10 gm 115 ft/sec in 10 ft
2.2	4.9	<10	9.3	Missiles (masonry)10 lbs 10 ft/sec in 26 ft
2.4	4.6	<10	10	Missiles (masonry) 10 lbs 10 ft/sec in 10 ft
2.5	4.5	<10	11	Eardrum rupture assuming pressure reflection
4.3	3.1	<10	25	Displacement of man 160 lb 10 ft/sec in 1 ft
5.0	2.8	<10	31	Eardrum rupture, assuming no pressure reflection
6.0	2.6	<10	37	Lung damage assuming pressure reflection
15.0	1.5	500	120	Lung damage assuming no pressure reflection

Computed and prepared by Bowen(86)

Table 17

Comparative Weapons Effect Data
Applicable to Indicated Blast Criteria
for a 10 MT Surface Burst at Sea Level

Incident over-pressure psi	Range in mi	Initial ionizing radiation rem	Thermal radiation cal/cm^2	Blast criteria for primary, secondary and tertiary effects
1.3	16	<10	7.2	Displacement of man 160 lb 10 ft/sec in 58 ft
1.5	14	<10	9.5	Missiles (masonry) 10 lb 10 ft/sec in 58 ft
1.8	12	<10	13	Displacement of man 160 lb 10 ft/sec in 10 ft
2.1	11	<10	16	Missiles (masonry) 10 lb 10 ft/sec in 10 ft
2.2	11	<10	16	Missiles (glass) 10 gm 115 ft/sec in 10 ft
2.5	9.7	<10	21	Eardrum rupture assuming pressure reflection
4.3	6.8	<10	46	Displacement of man 160 lb 10 ft/sec in 1 ft
5.0	6.1	<10	58	Eardrum rupture assuming no pressure reflection
6.0	5.5	<10	74	Lung damage assuming pressure reflection
15.0	3.3	10	220	Lung damage assuming no pressure reflection

Computed and prepared by Bowen(86)

Summary

1. The scope and nature of biological blast effects were noted and briefly described.

2. Four categories of blast hazards were defined as follows:

   a. primary effects due to blast-produced overpressures and their reflections,

   b. secondary effects from damage following the impact of penetrating and nonpenetrating missiles energized by blast pressures and winds and gravity,

   c. tertiary effects involving injuries occurring as a consequence of displacement of a biological target by blast shock and winds, and

   d. miscellaneous injuries due to ground shock, dust and blast associated thermal phenomena.

3. The character of primary, secondary and tertiary blast hazards was described to emphasize the seriousness of blast-produced injuries.

4. In further emphasis of the danger, the occurrence of combined injuries from pressure, missiles and displacement was discussed and actual experiences in the Texas City Disaster of 1947 involving over 550 dead or missing, 800 hospitalizations, and between 3000 and 4000 additional casualties were cited to make clear the need for immediate and prolonged care to avoid fatalities if blast injuries are allowed to occur.

5. Selected data relating environmental conditions defining gross biologic damage from overpressures, missiles and impact loading were presented as background for fixing tentative, but conservative threshold criteria for human casualties from blast.

6. A casualty was defined simply as an individual sufficiently injured to be unable to care for himself and thus become a burden to someone else.

7. The tentative criteria adopted were as follows:

   a. Primary blast effects based on (1) lung damage at an

incident and maximal pressure of 15 psi and at 6 psi incident overpressure for conditions wherein a reflection to 15 psi max occurs, and (2) rupture of the eardrum beginning at an incident and maximal overpressure of 5 psi and at an incident overpressure of 2.5 psi under circumstances where reflection to 5 psi max will occur.

b. Secondary blast effects for penetrating and nonpenetrating missiles; the former referred to a 10 gm glass missile having a velocity of 115 ft/sec which has a 1 per cent probability of traversing the abdominal wall of a dog and entering the abdominal cavity; the latter was estimated considering a 10 lb masonry missile travelling 10 ft/sec as having only a slight chance of producing significant head and body injury.

c. Tertiary blast effects assumed damage only on decelerative impact, and displacements involving velocities of 10 ft/sec for a 160 lb man were considered low enough to avoid significant numbers of serious head and skeletal injuries.

8. The tentative criteria arbitrarily adopted to "fix" the threshold for blast casualties were related to nuclear weapons of 1 and 10 MT yield, surface detonated at sea level, in terms of overpressures, ranges and areas involved.

9. The maximal ranges at which primary effects would be noted were estimated as follows:

Effect	1 MT	10 MT
Eardrum rupture	4.5 mi	9.7 mi
Lung damage	2.6 mi	5.5 mi

10. The estimated maximal areas involved for primary effects were:

Effect	1 MT	10 MT
Eardrum rupture	64 sq mi	300 sq mi
Lung damage	21 sq mi	95 sq mi

11. The distance travelled by a blast energized missile before impact was noted as one critical factor in determining impact velocity.

12. The estimated ranges at which casualties from penetrating and nonpenetrating missiles would begin for the 1 and 10 MT surface bursts at sea level were:

Type Missile	Weight Missile	Distance to impact	Range 1 MT	Range 10 MT
Glass	10 gm	10 ft	4.9 mi	11 mi
Masonry	10 lb	10 ft	4.6 mi	11 mi
Masonry	10 lb	26 ft	4.9 mi	
Masonry	10 lb	58 ft		14 mi

13. The corresponding estimated areas over which missile casualties could be expected were:

Type Missile	Weight Missile	Distance to impact	Area 1 MT	Area 10 MT
Glass	10 gm	10 ft	75 sq mi	380 sq mi
Masonry	10 lb	10 ft	66 sq mi	380 sq mi
Masonry	10 lb	26 ft	75 sq mi	
Masonry	10 lb	58 ft		620 sq mi

14. Casualties due to displacement, among other things, were noted to involve the distance of travel before impact.

15. Thus, the estimated ranges over which casualties could be expected for the 160 lb human travelling 10 ft/sec varied with displacement distance at impact for the surface bursts at sea level as follows:

Travel before impact 10 ft per second	Range 1 MT	Range 10 MT
1 ft	3.1 mi	6.8 mi
2 ft	3.7 mi	8.0 mi
5 ft	4.7 mi	10 mi
10 ft	5.1 mi	12 mi
28 ft	5.5 mi	
58 ft		16 mi

16. The corresponding areas involved for displacement-related human casualties were estimated as:

Travel before impact	Areas 1 MT	Areas 10 MT
1 ft	30 sq mi	150 sq mi
2 ft	43 sq mi	200 sq mi
5 ft	69 sq mi	310 sq mi
10 ft	82 sq mi	450 sq mi
28 ft	95 sq mi	
58 ft		800 sq mi

17. For megaton yields the estimated displacement hazard from blast reached to greater ranges from ground zero than those estimated for missile damage and the latter to greater distances than those expected for pressure injury.

18. Judging by the estimated areas involved, about 5 per cent of the blast hazard from a 10 MT surface burst arises from casualties related directly to overpressure while near 95 per cent concern damage from missiles and displacement.

19. The relation of nuclear blast effects to thermal and initial ionizing radiation were tabulated in preliminary form.

20. The absence of any hazard from initial ionizing radiation from a 10 MT surface burst over the entire range noted for blast casualties in to a distance of 3.3 mi (15 psi, 10 rem initial ionizing radiation, 220 cal/cm^2) was pointed out.

21. The tabular data presented for "free-field" effects of megaton surface bursts emphasized the short ranges for danger from initial ionizing radiation compared with the ranges for the several blast hazards; likewise, the relatively greater distances compared with blast effects, for potential damage from thermal radiation were noted.

22. The logic of seeking appropriate cover to avoid human casualties from thermal, displacement, missile and pressure effects was discussed and the associated gain in shielding from residual and initial radiation was mentioned.

23. The need for estimating residual radiation levels expected at very close ranges from ground zero was thought critical, for any assessment of the total "cost" of nuclear war to a nation requires appreciation of the total hazards, including those to the entire population, from all untoward effects which occur as a consequence of nuclear explosions.

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Dr. WHITE. I plan in the next few minutes to present the introduction and the summary of the prepared statement, following which details will be given as time allows, and as fits the pleasure of the committee. This presentation, though generally concerned with biological effects of airborne blast phenomena, will be limited to deal briefly with three main topics. First the scope and nature of the several blast hazards will be delineated. Secondly, the tentative criteria for threshold damage to humans will be set forth. Thirdly, these criteria will be related to nuclear weapons in terms of ground ranges and areas involved for the 1 mt. and 10 mt. surface detonations at sea level, and to allow appreciation of relative importance of blast with other effects, appropriate values for ionizing and thermal radiation will be noted if time allows.

It is useful to categorize the blast hazards into four categories as follows, and this summary is in the prepared statement.

First, primary blast effects are those due to overpressures and their reflections. Secondly, secondary effects are due to damage following the impact of penetrating and nonpenetrating missiles which are energized by blast pressures and winds and sometimes by gravity following the passage of the pressure pulse.

Thirdly, tertiary blast effects involve injuries occurring as a consequence of displacement of a biological target by blast shock and winds. Fourthly and last, miscellaneous injuries which will be only mentioned here are those due to ground shock, dust, and blast associated thermal phenomena which are not directly related with primary thermal radiation.

In the prepared statement the character of primary, secondary, and tertiary blast hazards was described to emphasize the seriousness of blast produced injuries. In further emphasis of the danger, the occurrence of combined injuries from pressure, missiles, and displacement was discussed and some actual experiences in the Texas City disaster of 1947 involving over 550 dead or missing, 800 hospitalizations and between 3,000 and 4,000 additional casualties were cited to make clear the need for immediate and prolonged care to avoid fatalities if blast injuries are allowed to occur.

Selected data relating environmental conditions defining gross biologic damage from overpressures, missiles, and impact loading were presented as background for fixing tentative but conservative threshold criteria for human casualties from blast. A casualty was defined quite simply as an individual sufficiently injured to be unable to care for himself, and thus become a burden to someone else.

One might interpolate here and say that this concept involves trying to fix the ranges from nuclear bursts at which blast casualties from the several effects—pressure, missiles, and displacement—would approach a minimum. To say this another way, if one starts way out from ground zero and moves in, these criteria are calculated to show where there is a significant increase in blast casualties. They are not fixed to avoid serious injuries completely, but they are chosen so that these injuries are unlikely to be great in number.

The tentative criteria adopted were as follows:

For primary blast effects, one was based on lung damage, and this was fixed at an incident and maximum pressure of 15 pounds per square inch, and at 6 p.s.i. incident overpressure for conditions wherein a reflection to 15 p.s.i. max could occur.

Secondly, primary criteria were noted in terms of the tolerance of the eardrum, beginning at incident and maximal overpressures of 5 p.s.i., and incident overpressure of 2.5 p.s.i. under certain circumstances where reflection to 5 p.s.i. max could occur.

The criteria for secondary blast effects for penetrating and nonpenetrating missiles were set in the case of the former using data applying to a 10 gram glass missile having a velocity of 115 feet per second, which has a 1 percent probability of traversing the abdominal wall of the dog and entering the abdominal cavity. The latter was estimated considering a 10 pound masonry missile, traveling 10 feet per second, as having only a slight chance of producing significant head or body injury.

For tertiary blast effects, damage was assumed only on decelerative impact, and displacements involving velocities of 10 feet per second for a 160-pound man were considered low enough to avoid significant numbers of serious head and skeletal injuries.

These tentative criteria arbitrarily adopted to fix the threshold for blast casualties were related to nuclear weapons of 1 and 10 mt. yield surface detonated at sea level in terms of overpressures, ranges, and areas involved.

The maximal ranges at which the primary effects or those due to pressure would be noted were estimated as follows:

For rupture of the eardrum, 4.5 miles from the 1 mt. burst, and 9.7 miles from a 10 mt. detonation.

Lung damage at 2.6 and 5.5, respectively, from 1 and 10 mt. explosions.

The estimated maximal areas involved for primary effects were for eardrum rupture 64 square miles and 300 square miles for 1 and 10 mt. weapons; and lung damage at 21 square miles and 95 square miles for the corresponding smaller and larger yields.

Representative HOLIFIELD. I have lost the place on your chart. Where are you reading?

Dr. WHITE. I am now at No. 10 in the summary, Mr. Holifield.

Representative HOLIFIELD. Thank you.

Dr. WHITE. The distance traveled by a blast energized missile before impact was noted as one critical factor in determining impact velocity. I might explain this a bit. If a missile arises from a window at arrival of blast front and winds, it then gains velocity fairly quickly, but it takes time, and the missile has to travel a certain distance. In the field, for example, if one places a missile trap 10 feet from a window, the velocities obtained are likely to be different than those noted were the missile trap placed 2 feet or 5 feet or 20 feet from the window.

What I am saying is that if one plots a velocity distance diagram, the missile has to go so many feet to reach x velocity, and so many more feet to reach y velocity. Eventually with increasing distance of travel, the missile reaches a maximum velocity. This forces one to specify how far a missile travels before it strikes a biological target. These distances will be specified arbitrarily below.

The estimated ranges at which casualties from penetrating and nonpenetrating missiles would begin for the one MT surface burst at sea level were, for the glass missile of 10 grams in weight, moving 10 feet before impact, 4.9 miles and 11 miles for the 1 and 10 MT yield. For

the masonry missile, nonpenetrating, 10 pounds in weight also——

Senator HICKENLOOPER. Would you mind an interruption, Dr. White?

Dr. WHITE. No, sir.

Senator HICKENLOOPER. Just to make clear your table here, do I understand that a 10-gram glass missile, under the heading "Distance to impact," means that if you are 4.9 miles away from the center of the blast and the glass missile is 10 feet away from you——

Dr. WHITE. That arose 10 feet away from you. It started to move at that distance from you.

Senator HICKENLOOPER. It started to move a distance 10 feet away.

Dr. WHITE. It would have a velocity of 115 feet per second when it hit you.

Senator HICKENLOOPER. So that the 10 feet is not 10 feet from the point of blast.

Dr. WHITE. No.

Senator HICKENLOOPER. But the 10 feet from the point of casualty?

Dr. WHITE. The 10 feet refers to distance of missile travel before impact.

Senator HICKENLOOPER. Thank you. I just wanted to get that clear.

Dr. WHITE. Yes, sir. For the 10-pound masonry missile, also traveling 10 feet before impact with the target, the ranges were estimated at 4.6 and 11 miles for the two yields under consideration. If one allowed the 10-pound masonry missile for the one MT case to move until it reached a 10 feet per second maximum velocity, it would move 26 feet where the range was 4.9 miles. The same missile for the 10 MT case would reach a velocity of 10 feet per second after 58 feet of travel at 14 miles from the epicenter. This means that the overpressure would be lower if you allow the winds to act on the missile longer. It keeps accelerating until maximum velocity occurs. If one wants to put this in terms of range and keep the velocity at 10 feet per second, the farther you let the missile move—up until it gets maximum velocity—the less the overpressure and the greater the range.

The expected corresponding areas over which missile casualties could be expected were, for a glass missile, 10 grams in weight, again traveling 10 feet before impact: 75 square miles and 380 square miles for the 1 and 10 MT yields respectively. For masonry missile of 10 pounds, also moving 10 feet before impact at 10 feet per second, the corresponding areas involved were estimated at 66 and 380 square miles. If one lets the missile move 26 and 58 feet for the 1 and 10 MT case, respectively, the corresponding areas are 75 and 620 square miles.

Casualties due to displacement—among other things as was the case with the missiles—were noted to involve the distance of travel before impact.

Representative HOLIFIELD. You mean by displacement changing positions of the human body?

Dr. WHITE. I mean actual picking up of a man and moving him through the air. This concept allows one to "treat" man as a missile. We were fortunate enough at a 5 psi station in one of the 1957 shots in Nevada to photograph the time-displacement history of a 160-pound dummy, and were able from analysis of the movies to determine the maximal velocity reached by this "creature" at about 21 feet per second. This velocity developed in five-tenths of a second. The total displace-

ment of the dummy was near 22 feet downwind. It was this piece of empirical information that helped greatly in getting an analytical "handle" on the "treatment" of man as a missile.

Likewise in the Nevada experience on another shot, where the overpressure was about 7 pounds per square inch the maximal velocities reached by standing and prone dummies were not determined. But the total displacement of the standing dummy was 256 feet downwind and 44 feet to the right.

Representative HOLIFIELD. This is what size bomb, if you remember?

Dr. WHITE. I think I will ask Mr. Corsbie if he knows the yield of that shot.

Representative HOLIFIELD. Mr. Corsbie, do you remember that yield?

Mr. CORSBIE. That was a 43 kiloton fired from about a 700 foot tower.

Representative HOLIFIELD. How far was the dummy from the tower?

Dr. WHITE. This was approximately—I may have to correct this—either 3,406 feet or 3,604 feet. The correct distance was 3,406 feet.

Representative HOLIFIELD. More than a half mile?

Dr. WHITE. The measured pressure there was 6.9 pounds per square inch and the pressure of the wind, which is the difference between the pressure measured head on to the advancing shock front and the pressure measured side on, was 15.4 pounds per square inch. For orientation it is useful to know that hurricane winds of about 120 miles an hour have a dynamic pressure or "Q" of approximately 0.2 of a pound per square inch. These are tremendous winds.

Representative HOLIFIELD. Then the wind is much greater than the worst hurricanes that have hit our coasts?

Dr. WHITE. Yes. This, ignoring other factors, is a function of the overpressured yield and the range, of course. The usual quoted dynamic pressure for 5 pounds per square inch for small yields is approximately 0.5 or 0.7 pound per square inch.

Representative HOLIFIELD. How high does it go in the case of a 10 megaton?

Dr. WHITE. I can't answer that out of my head. I would have to look it up. I don't think that the Q's associated with a given overpressure like 5 p.s.i. which will occur at considerable range will be much higher than for small yields. I am no blast physicist, but I think this is the case. But the winds, however, will last much longer.

Representative HOLIFIELD. Does the lower chart on page 33 mean that a body 5.5 miles from point zero would travel 28 feet?

Dr. WHITE. Yes, which is the best current estimate for the 1 MT surface burst. That range, of course, fixes an overpressure, but that range also "fixes" a velocity of 10 feet per second, which was adopted in the criteria. Ten feet per second was chosen as the velocity at impact for just beginning casualties based on what biological information is known about impact loads necessary to fracture the skull, to fracture the heel bones and the bones of the feet, and the lower extremeties.

Representative HOLIFIELD. And in the case of the 10-megaton bomb, a body would travel 58 feet over a range of 16 miles?

Dr. WHITE. At 16 miles.

Representative HOLIFIELD. At 16 miles the body will travel 58 feet before impact?

Dr. WHITE. That is correct, unless impact with some object occurred before maximal velocity are reached. The associated overpressure is quite low and is given in one of the tables on page 25, table 14. For the 16-mile range, 1.3 p.s.i. was estimated as the pressure at which it would take a 160-pound man, 58 feet to reach a velocity of 10 feet per second.

It might be instructive to look at item 15 on page 33 of the summary, which gives estimated ranges over which casualties could be expected to begin for the 160-pound human traveling 10 feet per second. These, since they vary with displacement distances before impact were worked out for distances of one foot of travel before impact, 2, 5, 10, 28, and 58, and respectively for these distances of travel—the estimated ranges from the 1 mt. were 3.1, 3.7, 4.7, 5.1 and 5.5 miles. Of course, these figures are larger for the 10 mt. surface burst at sea level, being 6.8, 8, 10, 12 and 16 miles.

The corresponding areas involved for displacement-related casualties were estimated for the 1, 2, 5, 10, and 28 feet displacements to be 30, 43, 69, 82, and 95 square miles respectively for the 1 mt. case. Corresponding with the 1, 2, 5, 10, and 58 foot displacements at impact, 150, 200, 310, 450 and 800 square miles respectively applied to the 10 mt. surface burst at sea level.

For megaton yields, the estimated displacement hazard from blast reached a greater range from ground zero than those expected for pressure injury. I will call your attention to a summary graph of the criteria which appears on page 24a as figure 7 in the prepared statement (p. 343). The figure summarizes blast damage due to overpressure, missiles and displacement in terms of the threshold criteria assumed, and notes the peak overpressures at which these occur for the 1 mt surface burst on the top scale. The area in square miles and the range in miles are given on the bottom scale.

Figure 8 (p. 344), shows similar information in summary for the 10 mt surface burst at sea level.

Judging by the estimated areas involved, about 5 percent of the blast hazard from a 10 mt surface burst arises from casualties related directly overpressure, while 95 percent concerns damage from missiles and displacement.

Representative HOLIFIELD. Of course, this envisages a man standing on the surface of the earth, or on some exposed area above ground, I should have said?

Dr. WHITE. Yes. This is a very complex matter, and I am glad you asked the question. What appears in most weapons effects manuals are what I like to call the free-field effects. They are the ranges for the overpressures and the thermal pulses, and the prompt radiation, assuming a certain atmospheric condition, height of burst, and so on, but over fairly flat terrain in which there are no buildings or structures in the way. There are great difficulties in estimating accurately what the overpressures and winds and missile hazards will be wherever the biologic target is located. If a man is in the open, of course, he faces grave difficulties from the initial thermal radiation. However, it is unlikely that everybody in the United States, if this country were ever attacked, would be outdoors at one time. The

shielding effects of houses and other structures are quite great as far as thermal is concerned. Not so much for ionizing radiation. But the missile hazard can be worse for a person indoors than outdoors.

Representative HOLIFIELD. Not only the fact that the human body becomes a missile, but the fact that any fractionation of the buildings, bricks, and timbers and that sort of thing would automatically become lethal missiles.

Dr. WHITE. That is right. We have had some experience in Nevada measuring missile velocities in houses and studying displacements inside blast protective shelters which were deliberately tested open. We know a bit about how the pressure inside and outside is related to the wind in the doorway—the entryway—and how the wind pressures at the site of exposed animals varied under the circumstances of the test. It is very important in estimating the blast hazard to remember that the free field effects give one a "handle" for circumstances that do not in themselves take into consideration the geometry of exposure. In terms of pressure reflections, this can certainly be critical. This is why there were two overpressures given for the primary blast hazard.

For example, if one exposes guinea pigs in a cage bolted against the closed end of a shock tube—the Foundation operates such a shock tube in Albuquerque for the AEC—and exposes animals in sufficient numbers and at different pressures to define the mortality curve as a function of maximum pressure, the figure for the P–50, or the pressure that will kill 50 percent of the guinea pigs is approximately 37 p.s.i., when the cage is right against the end plate. There is an incident pressure of a little less than one-third the maximum of 37 that comes down the shock tube, passes over the animal, and almost instantaneously reflects to a maximum of 37 pounds per square inch, the P–50. By the simple expedient of moving the case 1 foot from the end plate—and this was worked out for 1 inch, 2 inches, 6 inches, and 1 foot distances from the reflecting surface—in terms of the P maximum, the P–50 rises from 37 to almost 58 pounds per square inch.

Under these circumstances the animal does not "take" the maximum pressure all at once. He "sees" first the incident pressure pass by, which is about one-third of 58 p.s.i., say 18 or 20, and then 1.4 milliseconds later the reflected pressure comes back. So the pressure at the animal goes up in two steps. The most hazardous position to be, as far as primary blast damage is concerned, is against a reflecting surface facing the advancing front. If one moves away from the reflecting surface and allows the pressure to be applied on the average more slowly or in steps, this unfortunately increases the hazard from displacement. One has to play these things one against the other in deciding what makes sense if one indeed is interested, which most sensible people are, in protective measures.

Representative HOLIFIELD. Of course, if we did have an underground shelter, say 3 feet underground with a 1-foot concrete top on the shell 3 feet below the ground, you would automatically increase the chance of survival tremendously, would you not?

Dr. WHITE. This remark you have made is mentioned in the prepared statement. You are quite right. Shielding of that character will prevent prompt thermal effects into a certain range which is very

close to the detonation, even providing the shelter is open. If the shelter is closed and does not fail, the thermal hazard will not occur.

In WT–1179, there are documented some experiences in 1955, exposing animals in underground heavy structures 1,050 feet from a towed-detonated weapon approximately 1½ nominal yield.

Representative HOLIFIELD. Will you please explain that for the record, 1½ nominal yield?

Dr. WHITE. Approximately 30 kilotons. The maximal overpressures that existed outside this structure were between two- and threefold those estimated as right under the Hiroshima-Nagasaki explosions. The animals inside were singed.

Representative HOLIFIELD. Was this an open shelter?

Dr. WHITE. Yes, sir. The entryway looked right at the bomb, and if one were going to enter the shelter, it was necessary to walk down stairs, turn right, turn left and turn left again to get into the main chamber. The animals were singed in those positions where the wind played over them the most. We don't quite understand the genesis of these thermal lesions. This is one of the miscellaneous blast effects. It is unlikely that they were due to reflections or scattering of the direct thermal pulse from the burst. They were probably due, and I say probably on purpose, to aerodynamic heating, to very hot gas carried into the structure during the time that it was filling with gas during the pressure buildup phase, and/or perhaps to hot dust particles which were carried in with the winds. So a shelter that you point out might be useful for fallout, I assume, needs to be looked at from the point of view, is it open or is it closed, and what is likely to be the range from what yield, and if it is left open and the overpressures outside were high enough, there would be very high wind velocities in the doorway. It is quite simple, actually, to protect against displacement from such high velocity winds. This was achieved and tried out in the 1957 Nevada operation. Simple steel baffles or screens placed at 45° in front of the animals were sufficient to avoid any displacement whatsoever.

The relation of nuclear blast effects to thermal and ionizing radiation were tabulated in preliminary form. The absence of any significant hazard from initial ionizing radiation from a 10 mt. surface burst over the entire range noted for blast casualties into a distance of 3.3 miles from ground zero was pointed out. The estimated overpressure for this range was 15 pounds per square inch.

Using the data of Glasstone in the "Effects of Nuclear Weapons" for prompt radiation, 10 rem was estimated as the radiation at that distance, where, however, 220 calories per square centimeter could be expected, which emphasizes the great range of the thermal effect in unshielded conditions. It is instructive, I think, to call attention to some tables as follows:

There is a table (p. 345) which shows the various free field effects of biological interest as a function of range from ground zero for the 1 and 10 mt. surface burst at sea level. In the lefthand column, range in miles is noted. The incident overpressures follow this under P in the second column. The third column, headed "IR," gives values for ionizing radiation in rem. Also numbers for the thermal radiation are noted, and the velocities predicted at 10 feet

of displacement for a 160-pound man are included for the noted overpressures and ranges.

To pin this down a little more closely to the criteria used for estimating the threshold of blast casualties, I direct your attention to table 16 on page 349.) This table in the first column on the left shows overpressures varying from 1.9 to 15 p.s.i., which are the estimated overpressures that meet the criteria we have been discussing. These criteria are noted in the right-hand column.

The second column shows ranges from the 1 mt. surface burst to which this table applies and the initial ionizing radiation is noted in the third column. There is less than 10 rem estimated at all overpressures into a range of 2.6 miles, but at 15 p.s.i., which was one of the overpressures used for lung damage, assuming no pressure reflection in the case of exposure of man, at a range of 1.5 miles, a radiation level of 500 rem was estimated.

Representative HOLIFIELD. What is the reason for that?

Dr. WHITE. Mr. Holifield, I am not an expert in bomb phenomenology or in nuclear physics, but I believe that applies to the fact that the ionizing radiation, prompt, whether gamma or neutron, has a certain mean free path, or is attenuated in air. As one comes in from the periphery of an explosion, a range is reached inside of which the prompt radiation begins to rise fairly sharply. In this case for the 1 mt. yield at the 15 p.s.i. range of 15 miles, this has reached a very hazardous dose for unprotected people. To look at a similar situation for the 10 mt. surface burst, table 17 (p. 350) was prepared in a similar manner to the one just discussed.

The maximum ionizing radiation, initial dose in rem, into and including 15 p.s.i. at a range of 3.3 miles was only 10 rem. I wish to emphasize that from 15 p.s.i. out to 1.3 p.s.i. is a potential area for very serious blast casualties.

Representative HOLIFIELD. Also neutrons.

Dr. WHITE. The rem dose includes the neutrons.

Representative HOLIFIELD. It does?

Dr. WHITE. Yes, sir. This is combined dose from neutrons and gammas based on the information in "Effects of Nuclear Weapons" for the surface burst.

Representative HOSMER. Table 17 (p. 350), the last line of figures on the ionizing radiation, is that correct, 3.3?

Dr. WHITE. At 3.3 miles, the expected initial ionizing radiation is 10 rem.

Representative HOSMER. That is correct, then?

Dr. WHITE. Yes, thermal load is high, 220 calories per square centimeter.

The tabular data presented for free field effects emphasized the short ranges for danger from initial ionizing radiation compared with the ranges of the several blast hazards. Likewise, the relatively greater distances compared with blast effects for potential damage from thermal radiation were noted.

The logic of seeking appropriate cover, as the chairman pointed out a little while ago, to avoid human casualties from thermal, displacements, missiles, and pressure effects was briefly discussed, and the associated gain in shielding provided by the structure from residual and initial radiation was mentioned.

The need for estimating residual radiation levels expected at very close ranges from ground zero was thought critical, for any assessment of the total cost of nuclear wear to a nation requires appreciation of the total hazards, including those to the entire population, whether they live in the country or suburban areas or the urban areas, from all untoward effects which occur from consequences of nuclear explosions.

That concludes my statement, Mr. Chairman.

Representative HOLIFIELD. It is obvious that you have given us a very carefully prepared statement here. It is also obvious that there is so much in it we are not in a position to question you at length on it. We only received this copy, as you know, as you came to the stand.

I regret we didn't have it earlier so we could have studied it more. I am not blaming you for that situation. I know the reasons for it.

From a professional standpoint, you have confidence in the figures you have given here?

Dr. WHITE. I have taken pains in the statement, Mr. Holifield, to point out that these criteria are tentative. One is always on uncertain ground to some extent in attempting to extrapolate form animal data to humans. The criteria are conservative, and they are only very few in number. For instance, we have had time to deal only with the 10 gram glass missile. What about missiles of other weights and sizes, particularly as far as a serious hazard is concerned? What are the velocities as a function of missile mass which will injure the eye? Such data, as far as I am aware, are not available for glass missiles. There is some information on small steel spheres, which we are in the process of obtaining from the men who did the work.

I suspect that this analysis perhaps underestimates a little bit the range and the seriousness of the missile hazard. It might overestimate somewhat the ranges over which the displacement casualties can be expected, and probably from a realistic point of view, is also on the conservative side for the primary effects, namely, those due to pressure.

One reason I say the latter concerns the problem that you pointed out a little while ago. Free-field overpressures are one thing, and the pressures that are going to occur inside houses and other structures such as factories and office buildings where many people are likely to be is another thing.

If one degrades the rate of the pressure rise a little, the hazard goes down markedly as will be noted later. As pointed out in the statement, in general one can say that for a given "fast" rising overpressure, the shorter the duration of the overpressure the less the hazard. Or one can say if the overpressure is quite short, measured in a few milliseconds, very high pressures can be tolerated.

The dog, for example, exposed to high explosive blast by Desaga in Germany during the Second World War was just killed at overpressures of approximately 220 j.s.i. when the duration was about 2 milliseconds. But the fatal overpressure fell to 75 p.s.i. for durations of approximately 12 milliseconds.

These data are fairly consistent with the work that Fisher, Krohn, and Zucherman did in Oxford, also during the war, and both the

German and British estimates of human tolerance to high-explosive-produced overpressures.

It is from these data that the word got spread around that man could tolerate 200 to 400 pounds per square inch.

I believe these figures are realistic for very short duration overpressures. We had a puzzling experience, however, in 1953, in one of the early structures that Mr. Corsbie's group was testing. To our great surprise fairly severe but nonfatal lung hemorrhage occurred in dogs exposed inside these structures to peak pressures ranging from 12 to 25 pounds per square inch. The overpressure durations were over several hundred milliseconds, however.

Now, we believe that there needs be no confusion about this. The research that is calculated to be realistic in terms of the long-duration overpressures produced by nuclear weapons appears simply to extend the early high-explosive blast research. The gap between the very long and the fairly short overpressures has not been filled to date. The criterion estimated here of about 15 p.s.i. for beginning lung hemorrhage—just at the threshold of lung hemorrhage, not fatality—was based on recent experiments done by Dr. Donald R. Richmond in Albuquerque, in which he exposed mice, rabbits, guinea pigs, and rats, to sharp-rising, long-duration overpressures which were reflected from the closed end of a shock tube.

The durations of the pressures were seconds long. The P–50's—or the pressures associated with 50 percent mortality—for these animals varied from about 30 to 39 pounds per square inch.

The size of the equipment available, meaning the hardware of the shock tube, is not large enough to expose dogs in the same way. But we have been able to expose dogs to step loads, and fatality has occurred at a crudely worked out P–50—I say crude only because there are not enough animals yet to make it statistically valid—between 50 and 60 pounds per square inch. If one wants to read, as one can in some places, that approximately 30 p.s.i. is safe for a man, this depends upon the duration of the pulse and whether 30 p.s.i. "goes on" all at once or not, because the rate of pressure rise is important, and whether the geometry is conducive to a reflection of 30 p.s.i. to like 90 to 120 pounds per square inch, which, if applied very rapidly, is very likely to be fatal to man.

One study has been done dealing with varying rates of rise of pressures of long duration, also by the staff working on the AEC project at Albuquerque, and if the time to P-Max is 30, 60, 90, or 150 milliseconds—these are not sharp rising pulses but slowly rising pulses—tolerance of the animal is very high judged on the basis of peak pressure.

The experiments for the dog involve exposures to well over 150 pounds per square inch, approaching 200 pounds per square inch without fatality.

There is very minimal lung damage of a nonserious character. There is failure of the eardrums, of course, and some hemorrhage in the middle ear and sinus cavities. At the higher pressures a new lesion occurred, which Dr. Richmond has described; namely, fractures of the small bones of the orbit. These "blow out" because the pressures transmitted from the eyeballs "loads" the thin bones of some

of the sinus cavities since the sinus cavities have not had time to reach equilibrium with the ambient overpressures, for they must "fill" through the small openings into them. So there is an imbalance of pressure and fracture ensues.

Thus, one must be quite cautious in stating or estimating human tolerance. It is well to know that enough water has gone under the bridge researchwise now to begin to understand the analytical situation. Progress in the future to be realistic and carry the laboratory work to the field situations is going to require considerable help from the physicists. If one wanted, for instance, to take what is now known of the biological blast effects and work out a much more dedetailed analysis than that presented here, but as complete as possible, and then against this backdrop attempt to assess the casualties in Japan from the blast point of view, one is going to be faced with the necessity of saying, What was the pressure where a given man was exposed? How fast did it rise? What was its peak? What was its approximate duration?

It will be worthwhile to do such an analysis of the Japanese data against the free-field effect estimates. But, as you are aware, it is necessary to know the dose where humans were exposed if one wants to analyze the radiation exposures in Japan, and it is just as important to try to fix the environment at the location of the biological target for blast and thermal effects.

It is all one and the same problem, but quite complex.

Representative HOLIFIELD. Are there any questions from the committee? If not, Dr. White, thank you very much for your very valuable testimony to the committee. We appreciate all the personal trouble you had to go to in order to get here by plane this morning in time for the hearing. I am sure that, as we study this complete document you have brought to us, we are going to be much better informed. When the public gets this material they will be very much better informed upon this subject.

Dr. WHITE. Thank you, sir, very much. I have been delighted to be here.

Representative HOLIFIELD. Our next witness will be Dr. Victor Bond, who will testify on the beta burns on the skin. Dr. Bond is presently the head of the Division of Microbiology, Medical Research Center, at Brookhaven National Laboratory. He has had 12 years of research experience on the effects of radiation, both in the laboratory and in the field of testing atomic devices. A vital part of this experience was gained as deputy director of the team that cared for the Marshallese natives following their exposure to fallout radiation during Operation Castle in 1954.

I know the observers of these hearings will take note of the fact that we have gone into the field and tried to get the people who have actually participated in these different scientific evaluations and experiments at the actual point of impact of the bomb testing in the field of biology and actually caring for the people who have been exposed.

Dr. Bond, it is a pleasure to have you with us this morning. You may proceed.

STATEMENT OF DR. VICTOR BOND,[1] DIRECTOR OF THE DIVISION OF MICROBIOLOGY, MEDICAL RESEARCH CENTER, BROOKHAVEN NATIONAL LABORATORY

Dr. BOND. Thank you, Mr. Holifield.

Mr. Chairman, members of the committee, my topic is confined to the high-level fallout field itself, since, of course, beta lesions are not a problem in the absence of high-level fallout.

The relative importance of beta, compared to gamma radiation in fallout material in terms of casualty production, has been subject to debate. Before the accidental exposure of the Marshallese and the Japanese fishermen in March of 1954, the tendency was to ignore fallout in general, and beta radiation from fallout in particular, as formidable injurious agents.

The events in March of 1954 served to demonstrate conclusively, first, that high level radioactive fallout can result in extremely widespread serious injury and even death, and second, that extensive beta lesions of the skin can result, in the absence of a lethal exposure to penetrating gamma radiation, in an unprepared population exposed to large amounts of radioactive fallout.

In the time allotted me I propose to review the nature and the extent of skin damage that might result from exposure to large amounts of radioactive fallout. In doing this I shall rely rather heavily on the Marshallese data, although other examples are, of course, available. I shall do this since the data represent a well documented example of fallout beta lesions in a sizable population of human beings, and since I observed and helped care for the individuals involved and thus can speak from personal experience.

With respect to the lesions that we saw in the Marshallese, and I shall use the term "beta lesions" since a very large percentage of the dose received by the skin surface in these individuals resulted from beta radiation, the Marshallese were showered with radioactive fallout following the detonation in March 1954 of a high yield thermonuclear device during weapon testing in the Pacific proving grounds.

The wind shifted unexpectedly following the detonation, leading to unexpected fallout in significant amounts being deposited on the atolls of Rongelap, Rongerik, and Uterik.

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Education: San Jose High School, California, 1937; University of California, Berkeley, A.B., 1943; University of California, San Francisco, M.D., 1945; University of California, Berkeley, Ph. D. in medical physics, 1952.
Positions: Head, Experimental Pathology Branch, U.S.N. Radiological Defense Laboratory, San Francisco, Calif., 1948–54; scientist, Medical Research Center, Brookhaven National Laboratory, Upton, Long Island, N.Y., 1955–57; head, Division of Microbiology, Medical Research Center, Brookhaven National Laboratory, 1957 to present.
Military: Medical officer, U.S. Navy, 1945–54, highest rank, lieutenant, Marine Corps, U.S. Navy; presently, lieutenant commander, Marine Corps, U.S. Naval Reserve, retired.
Fields of interest: Medicine, radiobiology, effects of radiation. Twelve years of research experience on the effects of radiation, both in the laboratory and in field testing of atomic devices.
Other activities and information: Participant and project officer in biological work involving field testing; deputy director of the medical team that cared for the Marshallese following exposure to fallout radiation. In 1958, chairman of subcommittee on biomedicine, NAS–NRC, to evaluate adequacy of research in nonmilitary defense. Presently member of the National Advisory Committee on Radiation, Public Health Service; Subcommittee on Hematology of the NAS–NRC Committee To Investigate the Effects of Atomic Radiation; Subcommittee on RBE of the NCRP; Subcommittee on Radiological Dosimetry, ICRU.
Professional organizations: American Physiological Society, New York Academy of Sciences, Radiation Research Society, Sigma Xi, and AAAS.

The bomb was exploded on Bikini Atoll. At Rongelap and Alinginae atolls, a total of 82 persons were exposed to fallout. At Rongerik, farther away, 28 American servicemen were exposed, and at Uterik Atoll a total of 157 Marshallese were exposed.

Representative HOLIFIELD. These islands were approximately 100 miles from bomb zero?

Dr. BOND. The persons I wish to speak about, mainly, were 105 nautical miles from the point of detonation.

Reprsentative HOSMER. Doctor, there is another thing I think we ought to make clear at this point. The word "fallout" is such a nebulous term.

Dr. BOND. I am speaking of close-in high-level fallout and not the worldwide fallout that has been in the newspapers recently.

Representative HOSMER. That is the prompt fallout?

Dr. BOND. Prompt fallout and not worldwide fallout. This is fallout that occurs up to a few hundred miles from the weapon within a matter of hours following detonation.

The 64 Marshalese individuals on the island of Rongelap, 105 nautical miles from the point of detonation, received the largest exposure, and I shall confine my remarks to this group, as an example of beta burns.

The fallout was visible on Rongelap. It was described as snowlike and began falling approximately 5 hours after the detonation. The material was deposited on the ground and on the thatched roof houses as well as on the clothes, hair, and skin of the people. The individuals remained on the island for approximately 2 days, at which time they were transferred to the U.S. Naval Station at Kwajalein for medical observation.

No dosimeters were present on the island at the time of the detonation, and the doses of gamma radiation received were estimated from average readings of survey instruments held 3 feet above the ground, measured of the order of a week following the detonation. From these readings it was estimated that the Rongalapese received approximately 175 r. of penetrating gamma radiation, dose measured essentially free in air.

In addition to gamma exposure, these individuals received large doses of beta radiation to the skin. It is not possible to calculate with any reasonable degree of accuracy the dose to the skin from the beta radiation. Estimates involving the known minimal dose of radiation to cause hair loss indicate that the surface of the skin probably received of the order of 5,000 or more rads. However, that is a very uncertain figure.

With regard to symptomatology following exposure, with the exception of nausea in some two-thirds of the individuals during the first 2 days, and vomiting and diarrhea in a smaller percentage, no symptoms developed that could be ascribed to the penetrating gamma radiations. However, the penetrating radiation did result in marked peripheral blood changes. No deaths occurred as the result of irradiation, and all signs and symptoms, except the initial gastrointestinal symptoms were related to beta lesions of the skin.

Within the first 2 days of exposure a number experienced transitory itching and burning of the skin, and some complained of lacrymation, or watering of the eyes. No further signs or symptoms referable to

the skin were noted until about 2 weeks after exposure, when skin lesions and epilation, or loss of hair, was noted. Approximately 90 percent of the individuals showed some damage of this nature to the skin, and a smaller number showed spotty epilation or loss of hair.

The skin lesions first appeared as small, raised pigmented areas, which later coalesced to form extensive lesions of the skin. Most of the lesions were superficial and exhibited dry loss of skin surface much like a fairly severe sunburn.

Essentially all lesions were located in skin areas not covered by clothing—open skin—and they were most prevalent in the folded areas of the skin where perspiration would tend to collect. Even thin clothing apparently served to prevent visible damage.

The superficial lesions required no therapy beyond bland, soothing preparations, and apparently healed completely within a few weeks.

Some of the lesions, however, were deeper and showed wet desquamation, or loss of skin. Such lesions became infected and required treatment with antibiotics. The affected areas, with the exception of one, healed in a matter of weeks, with some residual scarring, atrophy, and depigmentation.

I think we can get a better idea of the nature of these lesions from pictures. The first (fig. 1, p. 384) is a picture showing the rather extensive lesions that occurred in these individuals. The picture was taken of this young boy 46 days after exposure. Note particularly the lesions on the neck, in the armpits, and at the belt-line areas where the fallout tended especially to collect.

The next picture (fig. 2, p. 385) represents rather extensive skin lesions on the neck of a woman. This is approximately 30 days after exposure to the fallout material. Note here the rather superficial nature of the lesions, like sunburn.

The next two pictures (figs. 3 and 4, pp. 386–387) illustrate the deeper, more severe lesions that healed more slowly. Note the more severe deep lesions on the feet in figure 3. Figure 4 shows the same lesion 6 months later. Note that healing has been essentially complete with some residual scarring, and one can see the depigmented area on the feet.

The next picture (fig. 5, p. 388) represents head lesions and spotty epilation in a young girl 28 days after exposure. Complete regrowth of normal hair is shown in the last picture (fig. 6, p. 389) taken 6 months after the exposure. The epilation was associated with lesions of the scalp indicating that the radiation was derived principally from material in contact with the skin and not from radiation from the ground, from the buildings, or from other surrounding materials.

On followup examinations in each of the 5 years since the accident none of the lesions has shown a tendency to break down, nor has premalignant or malignant change occurred.

In the course of initial observation on these people it was not necessary to hospitalize any of them. Some itching, but no pain was associated with the superficial lesions; however, by no standard could these people be considered incapacitated.

Mild pain was associated with the deeper lesions and some difficulty with walking resulted with the deeper lesions located on the feet. Here also, however, it would have been difficult to classify these in-

dividuals as incapacitated. If necessary, they could have performed essentially any task associated with daily living and survival.

So much for the Marshallese accident itself, indicating that extensive beta skin lesions can occur in the face of sublethal gamma exposure.

Now let us consider to what degree the Marshallese incident may be considered typical of what might occur in case of widespread fallout in populated areas of the United States from deliberate attack or accidents following nuclear detonations. What I say here represents my own opinions, of course.

I wish now to make it perfectly clear as we made it before that I am speaking of a disaster situation and large amounts of fallout. I am not dealing with routine peacetime operations and certainly not with the long-range fallout that has resulted in essentially worldwide, very low level contamination.

Representative HOLIFIELD. By the same token, in view of the fact that our examples here are chosen from a population 105 miles distant, we could expect that there would be a much greater concentration of beta fallout closer to bomb zero. Therefore the danger or the hazards from beta burns would be much greater within 10, 15, 20, 30, 40 miles than at the 105-mile distance. Is that true? The heavier particles would fall quicker.

Dr. BOND. I believe this is true. Certainly we can say from the Marshallese that in regions north of where these individuals were located the total fallout was greater and certainly the beta and gamma hazard would have been greater. I had intended to touch on that more, later, if I may.

Representative HOLIFIELD. Very well.

Dr. BOND. There are several factors that would make one consider the Marshallese incident the worst that could reasonably pertain in an otherwise undamaged area with respect to the relative hazard of beta radiation to gamma radiation.

Representative HOLIFIELD. This was the sentence that caused me to make this observation. There may be some incidents that will make it bad, but I think there are other incidents that would actually make it worse than the Marshall Islands. That is, proximity to the bomb blast, exposure to larger particles, and a thicker distribution of particles.

Dr. BOND. Yes, sir. Again I intend to touch on that a little later in the discussion.

The factors that would tend to make one consider the Marshallese incident to be the worst that one could reasonably expect is that the people were not alerted to the possible hazards of fallout and had no comprehension of what was happening. Thus they took no evasive action and made no effort to decontaminate themselves.

The American servicemen on Rongerik who were alert to danger and added clothing and decontaminated themselves showed considerably less effect. The Rongalapese were not evacuated from the contamianted island and thus were not decontaminated for two days following the detonation at which time a larger percetnage of the dose from the rapidly decaying fission products had already been received.

It is clear that the great bulk of the beta dose to the skin was derived from material deposited on the skin, and the habits of the Marshallese tended to maximize the deposition of the material on the skin. They wore rather scanty clothing and no shoes, and spent a good deal of time out of doors. The widespread use of thick hair oil aided in collecting the material on the head. The high humidity and sweating contributed by encouraging the material to collect on the skin.

Thus, one might conclude that the beta lesions would constitute an extensive problem only under the rather favorable conditions for it that were present in the Marshallese, and that the problem would essentially not exist should an American city be subjected to fallout radiation.

And further, one could conclude and I have heard this stated, that since beta lesions might be classified merely as a minor effect and something of a nuisance rather than an incapacitating or deadly one, that one might essentially ignore the problem in the face of the known serious consequences of the penetrating gamma radiation and other lethal modalities. This evaluation might pertain in general. However, it is necessary to inject a word of caution and present a possible other picture.

It is quite true that Americans spend a good deal of time inside. Under some circumstances, however, in warmer regions of the country and summertime, sizable numbers could be outside, with portions of the skin exposed. Also, especially in the peripheral zone from the point of detonation where windows may be shattered without other serious structural damage, it may not be necessary to be outside to have material deposited on one.

I think here the point you made, Mr. Holifield, would come in very well, that certainly closer in, or in a higher level fallout field, one could have more severe beta lesions and show a much higher gamma exposure than in the Marshallese.

Representative HOLIFIELD. I think your statement is quite well balanced. I had not had a chance to read this latter part of it. I think both of us could agree that if the people were properly informed about this hazard so that each individual understood it, the beta burns could be greatly reduced.

Dr. BOND. This is precisely the main point I wish to make.

Fallout on a previously devasted area would also present a serious picture. The fallout was visible in the Marshalls. It might not be in continental surroundings. One cannot ignore the possibility of fallout coming down in rain, in which event the clothing, if not removed, might provide the ideal situation for severe beta lesions. It is entirely possible under the chaotic conditions that would exist following an attack that no facilities for adequate decontamination may be available.

An educated, prepared population under almost any circumstances can do much to lessen the degree of damage or avoid damage completely.

However, in my opinion, it is questionable if most Americans at present are educated to the dangers of fallout in general, let alone the possible hazard from beta radiation.

Representative HOLIFIELD. I prefer the language of your prepared text there rather than your interpolation. I am going to read it at this time.

However, in my opinion, the vast majority of Americans are neither prepared, nor educated to the danger of fallout in general, let alone the possible hazard from beta radiation.

I think every word of that is true. I say that from a background of 4 years of study of the civil defense problem and holding many hundreds of hours of hearings on this subject.

Dr. BOND. Thank you, sir.

The main point I wish to make from the above remarks is that while beta lesions considered in the overall possible casualty situation may be a lesser consideration, it is still possible that appreciable segments of the involved population might develop beta lesions if exposed to fallout and no preventative measures were taken.

If this be the situation, the results potentially could be more serious than in the Marshallese, and much more than a mere nuisance, for the following reasons:

In the Marshallese, while the white count of the blood was markedly depressed, this and other immune mechanisms apparently were never impaired to the point at which individuals were unable to ward off possible invading organisms. With a larger dose of gamma radiation, and had the Marshallese been only a few miles north of where they were, they would have received a considerably larger dose, the situation might have been quite different. The white count would have fallen faster and it would have reached dangerously low levels as far as warding off infection is concerned. Then more of the lesions might have become infected and, in addition, the open lesions would provide a portal of entry for invading organisms, leading potentially to generalized infection. Infection is the problem of perhaps greatest magnitude with massive total body gamma exposure and with open skin lesions many might succumb that otherwise might survive.

This especially under conditions that undoubtedly would pertain, in which no medical care, or inadequate medical care would be available.

Thus, at present, I do not think we should ignore completely the beta lesion problem.

In summary, then, there can be no doubt that in a fallout field within hours and perhaps days of detonation, penetrating gamma radiation is the controlling hazard. Gamma radiation is the agent that kills primarly. However, there is also no doubt that extensive beta lesions have occurred, and might occur under some conditions in a fallout field. In an unprepared population unaware of the potential danger, beta skin lesions could represent a potentially serious hazard to appreciable numbers of individuals exposed.

In a well prepared population, however, educated to the potential hazard, the beta skin lesion problem would be minimal indeed, or nonexistent.

Thank you.

Representative HOLIFIELD. Thank you very much, Dr. Bond.

Representative HOSMER. I have one inquiry I would like to make of Dr. Bond.

These 64 people received 175 roentgens in an acute dose within 48 hours, which would correspond to 175 rad, I believe, for the whole body.

Dr. BOND. Yes, sir. For our purposes here, the roentgens and the rad can be interchanged.

Representative HOSMER. In your examinations have you up to this time found any incidence of leukemia?

Dr. BOND. Dr. Conard at Brookhaven has been carrying out yearly resurveys of the Marshallese under the auspices of the Atomic Energy Commission, and to date there has been no evidence of leukemia, or of changes in the blood that would lead one to suspect leukemia. One must realize, however, that only a relatively small population is involved.

Representative HOSMER. In this time, from 175 rad acute dose, have you picked up any other attributable effects over the longer range?

Dr. BOND. In general I would say that nothing has been picked up that could be ascribed specifically to the effects of radiation. Of course, changes are occurring in these people, but they are also occurring in the comparison population. In this small number of people to my knowledge, there has not been any late changes attributable to the gamma radiation.

Representative HOSMER. Has there been any reproduction in this group since that time?

Dr. BOND. Yes, sir. As of present, or at least a few months ago, there have been a total of some 18 babies born. An examination of these babies has revealed no abnormalities.

Representative HOSMER. Is that the probable number of babies that could have been expected to be born notwithstanding the accident?

Dr. BOND. Yes, sir; this is about par for the course.

Representative HOLIFIELD. I have two questions, Dr. Bond.

Beta emitters can be of short life and short range in their emission of energy. Will you please give us those two factors?

Dr. BOND. It is difficult to give these for a fission product field because one has a mixture of a large number of isotopes. The superficial nature of these lesions would lead one to believe that the energy here was relatively low, but I cannot attach a precise figure to the energy because it was not measured.

With regard to the half life of the beta emitters, their activity falls off roughly as does the decay of fission products in general. The vast bulk of the dose is delivered in the first few hours or days. But one cannot give a specific half life or a specific life to the beta emitting isotope aggregate in this case.

Representative HOLIFIELD. Thank you.

We have just received notice of a teller vote, and we will have to adjourn at this time. I appreciate very much your testimony, sir.

We will start the afternoon session at 2 p.m. with presentations on the acute effects of inhalation and injection. The afternoon session will be concluded with a panel discussion by a group of experts in the biological effects field who will attempt to clarify some of the major points of the controversy and resolve some of the major points of difference in the testimony which we received.

(Dr. Bond's full statement follows:)

Beta Radiation Skin Lesions (Beta Burns) From Fallout Radiations

INTRODUCTION

The relative importance of beta, compared to gamma radiation in fallout material in terms of casualty production has been subject to debate. Before the accidental exposure of the Marshallese (1) and the Japanese fishermen in March of 1954 (2), the tendency was to ignore fallout in general, and beta radiation from fallout in particular, as formidable injurious agents. The events in March of 1954 served to demonstrate conclusively, (1) that high-level radioactive fallout can result in extremely widespread serious injury and even death in an affected population, and (2) that extensive beta lesions of the skin can result, in the absence of a lethal exposure to penetrating gamma radiation, in an unprepared population exposed to large amounts of radioactive fallout. In this presentation the nature and extent of skin damage that might result from exposure to large amounts of radioactive fallout will be reviewed. In doing this heavy reliance will be placed on the Marshallese data (although other examples are available), since these data represent a well-documented example of fallout beta lesions in a sizable population of human beings, and since the author observed and helped care for the individuals involved and thus can speak from first-hand experience. Following this review of the nature of skin damage that can result from radioactive fallout, the possible degree to which the Marshallese situation might pertain under circumstances in the United States rather than in the mid-Pacific, and under circumstances in which the exposed population is better informed and better prepared, will be considered. Finally, an attempt will be made to place the potential beta lesion problem in perspective with regard to its seriousness compared to the hazard from the penetrating gamma radiation, which of course is invariably present.

THE MARSHALLESE INCIDENT

Now with respect to the beta lesions in the Marshallese (the affected areas are termed "beta lesions" since a very large percentage of the dose received by the skin surface resulted from beta radiation). These individuals were showered with radioactive fallout following the detonation in March 1954 of a high yield thermonuclear device during weapons testing at the Pacific Proving Grounds. The wind shifted unpredictably following the detonation, leading to unexpected fallout in significant amounts being deposited on the atolls of Rongelap, Rongerik and Uterik. The 64 Marshallese individuals on Rongelap at the time, 105 nautical miles from the detonation, received the largest exposure and I shall confine my remarks to this group. The fallout was visible on Rongelap, described as snowlike, and began falling approximately 5 hours after the detonation. The material was deposited on the ground and on the thatched-roof houses, as well as on the clothes, hair, and skin of the people. The individuals remained on the island for approximately 2 days, at which time they were transferred to the U.S. Naval Station at Kwajalein for medical observation.

No disimeters were present on the island, and the doses of gamma radiation received were estimated from average readings of survey instruments held 3 feet above the ground, of the order of a week following the detonation. From these readings it was estimated that the Rongalapese received approximately 175 r. of penetrating gamma radiation, dose measured essentially free in air. In addition to gamma exposure, these individuals received large doses of beta radiation in areas of the body in which the fallout material was adherent to the skin. It is not possible to calculate with any reasonable degree of accuracy the dose to the skin from beta radiation. Estimates involving the known minimal dose of radiation to cause hair loss or epilation indicate that the surface of the skin probably received of the order of 5,000 or more rads.

With regard to symptomatology, with the exception of nausea in some two-thirds of the individuals during the first 2 days, and vomiting and diarrhea in a smaller percentage, no symptoms developed that could be ascribed to penetrating gamma radiations. However, the penetrating radiation did result in marked peripheral blood count changes. No deaths occurred as the result of irradiation and all signs and symptoms except the initial gastrointestinal symptoms referred to were related to beta lesions of the skin.

Within the first 2 days of exposure a number experienced transitory itching and burning of the skin, and some complained of lacrymation. No further signs or symptoms referable to the skin were noted until about 2 weeks after exposure,

when skin lesions and epilation, or loss of hair, was noted. Approximately 90 percent of the individuals showed some damage of this nature to the skin, and a smaller number showed spotty epilation. The skin lesions first appeared as small, raised pigmented areas, which later coalesced to form more extensive lesions. The nature of these lesions is indicated in figures 1 to 6 (pp. 384 to 389). Most of the lesions were superficial and exhibited dry desquamation or loss of skin surface much like a fairly severe sunburn. Essentially all lesions were located in skin areas not covered by clothing, and they were most prevalent in the folded areas of skin where perspiration would tend to collect. Even thin clothing apparently served to prevent visible damage. The superficial lesions required no therapy beyond bland, soothing preparations, and apparently complete healing occurred within a few weeks. Some of the lesions were deeper, however, and showed wet desquamation or loss of skin. Such lesions became infected, and required treatment with antibiotics. The affected areas, with the exception of one, also healed in a matter of weeks, with some residual scarring, atrophy and depigmentation. On followup examinations in the 5 years since the accident (3–7), none of the lesions has shown a tendency to break down, nor has premalignant or malignant change occurred.

In the course of initial observation it was not necessary to hospitalize any of the patients. Some itching, but no pain was associated with the superficial lesions; however by no standard could these people be considered incapacitated. Mild pain was associated with the deeper lesions and some difficulty with walking resulted with the deeper lesions located on the feet. Here also, however, it would have been difficult to classify these individuals as incapacitated. If necessary, they could have performed essentially any task associated with daily living and survival.

APPLICATION OF THE MARSHALLESE RESULTS TO FALLOUT SITUATIONS IN GENERAL

So much for the Marshallese accident indicating that extensive beta skin lesions can occur in the face of sublethal gamma exposure; now let us consider to what degree the Marshallese incident may be considered typical of what might occur in case of widespread fallout in populated areas of the United States from deliberate attack, or from accidental nuclear weapon detonation. And I wish now to make it perfectly clear that I speak of a disaster situation, not routine peacetime operations and certainly not the long-range fallout that has resulted in essentially worldwide, very low-level contamination. There are several factors that would make one consider the Marshallese incident the worst that could reasonably pertain with respect to the hazard of beta radiation relative to that of gamma radiation (of course, populations might be exposed to considerably larger doses of both beta and gamma radiation than were the Marshallese). These people were not alerted to the possible hazards of fallout and had no comprehension of what was happening; thus they took no evasive action and made no effort to decontaminate themselves. American servicemen on a nearby contaminated island, who were more alert to the danger and added clothing and decontaminated themselves showed considerably less effect than did Marshallese comparably exposed. The Rongalapese were not evacuated from the contaminated island. and thus were not decontaminated for 2 days, at which time a large percentage of the dose from the rapidly decaying fission products had been received. It is clear that the great bulk of the beta dose was derived from material deposited on the skin, and the habits of the Marshallese tended to maximize the deposition of the material on the skin. They wore rather scanty clothing and no shoes, and spent a good deal of time out of doors. The use of thick hair oil aided in collecting the material on the head. The high humidity and sweating contributed by encouraging the material to collect on the skin. Thus one might conclude that the beta lesions would constitute an extensive problem only under the rather favorable conditions for it that were present in the Marshallese, and that the problem would essentially not exist should an American city be subjected to fallout radiation. And further, one could conclude that since beta skin lesions might be classified more as a minor effect and a nuisance rather than an incapacitating or deadly one, that one might essentially ignore the problem in the face of the known serious consequences of the penetrating gamma radiation and other potentially lethal modalities. This evaluation could pertain; however, it is necessary to inject a word of caution.

It is quite true that Americans spend a good deal of time inside; however, under some circumstances (warmer regions, summertime) sizable numbers could be outside, with portions of the skin exposed. Also, especially in the peripheral zone from the point of detonation where windows may be shattered without other serious structural damage, it may not be necessary to be outside to have material deposited on one. Fallout on a previously devastated area would present a like picture. The fallout was visible in the Marshalls; it might not be in continental surroundings. Even a thin layer of clothing protected the Marshallese from visible damage from fallout from the particular device employed. I do not know to what degree the beta energy spectrum from this device would represent closely that from more recent devices. One cannot ignore the possibility of fallout coming down in rain, in which event clothing, if not removed, might provide the ideal situation for severe beta lesions. It is entirely possible under the chaotic conditions that would exist following attack that no facilities for adequate decontamination may be available. An educated, prepared population under almost any circumstances can do much to lessen the degree of damage or avoid damage completely; however, in the author's opinion, the vast majority of Americans are neither prepared for, nor educated to the danger of fallout in general, let alone the possible hazard from beta radiation.

The main point to be made from the above remarks is that while beta lesions, considered in the overall possible casualty situations, undoubtedly is a lesser consideration, it is still possible that appreciable segments of the involved population might develop beta lesions if exposed to fallout and no preventive measures were taken. If this be the situation, the results potentially could be more serious than in the Marshallese, and much more than a mere nuisance, for the following reasons: in the Marshallese, while the white count of the blood was markedly depressed, this and other immune mechanisms apparently were never impaired to the point at which the individual was not able to ward off possible invading organisms. Further, the point of maximum effect on the white count occurred relatively late, in the fifth and sixth week, after the beta lesions were well on the way to healing. With a larger dose of gamma radiation, and had the Marshallese been only a few miles further north than they were at the time of fallout they would have received a considerably larger dose, the situation might have been different. The white count would have fallen faster, and it and other immune mechanisms would have been seriously affected. Then more of the lesions might have become infected, and in addition the open lesions would provide a portal of entry for invading organisms, leading potentially to generalized infection. Infection is the problem of perhaps greatest magnitude with massive total body gamma exposure, and with open skin lesions many might succumb that otherwise might survive. This especially under conditions that undoubtedly would pertain, in which no, or inadequate, medical care would be available. Thus, at present, I do not think we should ignore completely the beta lesion problem.

In summary, there can be no doubt that in a fallout field, within hours and perhaps days of detonation, penetrating gamma radiation is the controlling hazard. Gamma radiation is the agent that kills primarily. However, there also is no doubt that extensive beta lesions have occurred, and might occur under some conditions in a fallout field. In an unprepared population unaware of the potential danger, beta skin lesions could represent a potentially serious hazard to appreciable numbers of individuals exposed. In a well-prepared population educated to the potential hazard, the beta skin lesion problem would be minimal indeed.

SUMMARY

The Marshallese accident in March 1954 demonstrated clearly that extensive beta lesions of the skin, in the absence of a lethal dose of gamma radiation, can occur under some conditions in an unprepared population exposed to a high-level fallout radiations. The fallout began on Rongelap Atoll in the Marshall Islands approximately 5 hours after the detonation of a high yield thermonuclear device, and the 64 individuals on this atoll were evacuated approximately 2 days later. An estimated 175 r. of penetrating gamma radiation was delivered to the entire body, in addition to large doses of beta radiation to exposed areas of skin to which the fallout material clung. Beginning approximately 2 weeks after exposure, lesions of the skin appeared on some 90 percent

of the individuals. The affected areas included the head, and other locations where the material had deposited. Most of the lesions were superficial and healed rapidly. Some were deep and painful, and healed more slowly with some residual scarring. There has been no evidence to date of secondary breakdown or malignant change in these lesions.

Several factors pertained that made the Marshallese incident possibly the worst that could happen with respect to the relative importance of the beta hazard under conditions of fallout (of course populations could be exposed to much larger total doses of both beta and gamma radiations than were the Marshallese). The people were not educated nor prepared for the danger, and prolonged exposure without evasive action or decontamination occurred. The climatic conditions, conducive to relatively scanty clothing and outdoor existence also increased the degree of exposure. Under conditions of living in a temperate climate, many of these adverse factors would not normally be operative, and thus the beta problem would be expected to be minimal. However, it must be pointed out that exposure to contact beta radiation of a sizable number of individuals might occur in an uninformed population under some conditions (area of milder climate or in summer, individuals in buildings with shattered windows, fallout on a previously devastated area, clothed individuals caught in radioactive rain), or under chaotic conditions in which decontamination might not be possible. In these affected individuals, in the absence of decontamination, the resultant skin lesions in some could be much more serious than those seen in the Pacific islands. If the concomitant gamma exposure were higher than that received by the Marshallese, which it could easily be, the resultant depression of the white blood cell count, and of other immune mechanisms necessary to combat infection would be correspondingly more severe. Under these circumstances the open skin lesions could serve as a portal of entry for organisms, leading potentially to fatalities in individuals that might otherwise survive. Thus while the penetrating gamma hazard would by all odds be the most lethal agent in a fallout field, the beta skin hazard cannot be ignored and must be guarded against. Only in a population that is informed of the potential danger and is prepared will beta hazard be reduced to a minimum.

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FIGURE 1

FIGURE 1.—Extensive lesions, 46 days after exposure, on a young boy who wore little clothing at the time of exposure. Note particularly the lesions on the neck, in the armpits and at the beltline—areas where the fallout material tended especially to collect.

FIGURE 2

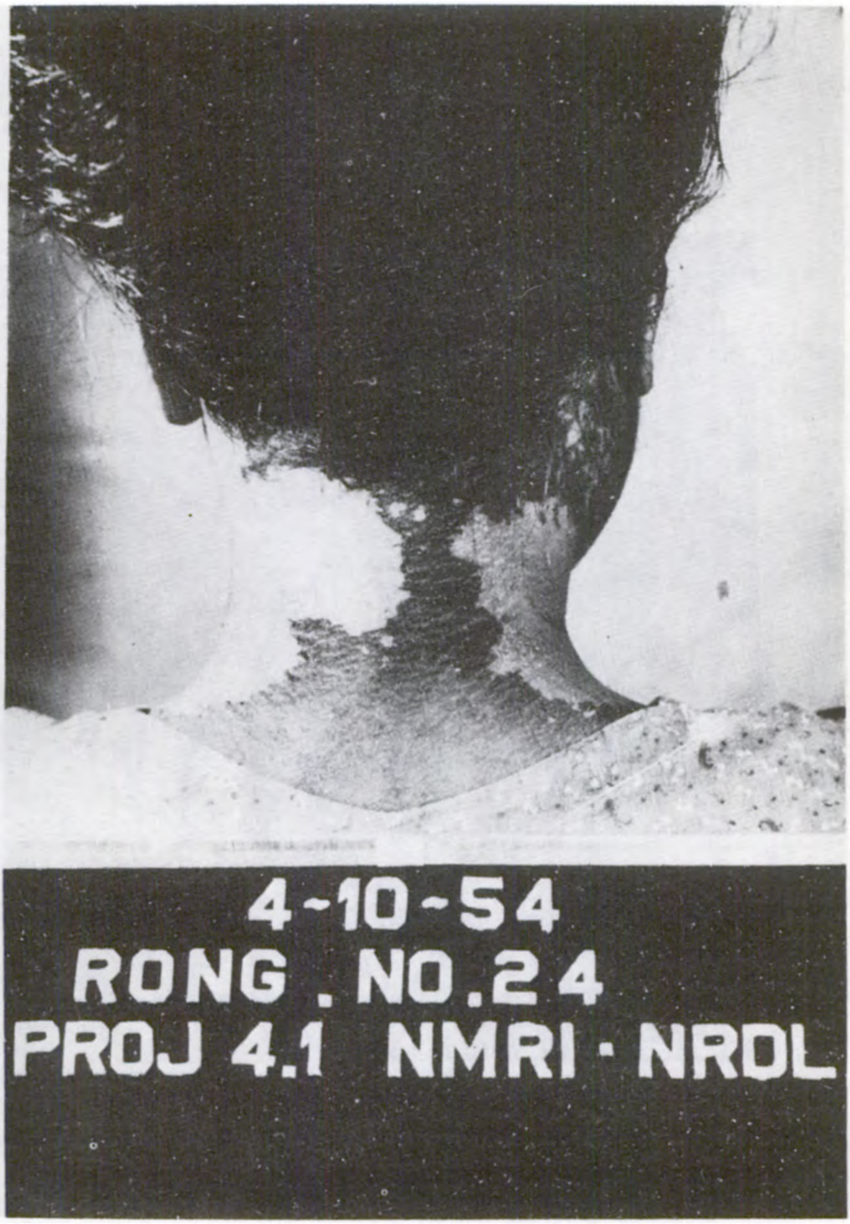

FIGURE 2.—Extensive neck lesions on a woman approximately 30 days after exposure. Note the superficial nature of the lesions, resembling severe sunburn.

FIGURE 3

FIGURE 3.—Deeper, more severe lesions that healed more slowly.

FIGURE 4

FIGURE 4.—The same lesion shown in figure 3, 6 months later. Healing is complete, with residual scarring, atrophy, and depigmentation.

FIGURE 5

FIGURE 5.—Head lesions, and spotty epilation in a young girl 28 days after exposure.

FIGURE 6

FIGURE 6.—Complete regrowth of normal hair in the same girl shown in figure 5, 6 months after exposure.

Representative HOLIFIELD. At this point I would like to submit for the record, a statement by Dr. Conard, and his associates on the Medical Survey of the Rongelap People, March 1958, 4 years after exposure to fallout; and the report of the Medical Status of the Rongelap People 5 Years After Exposure to Fallout Radiation, by Dr. Conard, head of the Marshall Island surveys.

(The material referred to follows:)

BNL 534 (T-135)
(Biology and Medicine)

MEDICAL SURVEY OF RONGELAP PEOPLE, MARCH 1958, FOUR YEARS AFTER EXPOSURE TO FALLOUT

ROBERT A. CONARD, M.D., JAMES S. ROBERTSON, M.D., PH.D., LEO M. MEYER, M.D., WATARU W. SUTOW, M.D., WILLIAM WOLINS, M.D., AUSTIN LOWREY, COL. (MC) USA, HAROLD C. URSCHEL, JR., LT. (MC) USN, JOHNNY M. BARTON, CAPT. (MC) USAF, MORRIS GOLDMAN, PH.D., HYMAN HECHTER, MAYNARD EICHER, RUSSELL K. CARVER, AND DAVID W. POTTER

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MEDICAL SURVEY OF RONGELAP PEOPLE, MARCH 1958, FOUR YEARS AFTER EXPOSURE TO FALLOUT

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Background

This report presents the results of a medical survey carried out in March 1958 on the Marshallese people of Rongelap Atoll who were accidentally exposed to radioactive fallout in March 1954. The accident occurred following the detonation of a high yield thermonuclear device during experiments at Bikini in the Pacific Proving Grounds. An unpredicted shift in winds caused a deposition of significant amounts of fallout on four inhabited Marshall Islands nearby and on 23 Japanese fishermen aboard their fishing vessel, the Lucky Dragon (see Figure 1.) Sixty-four inhabitants of the island of Rongelap, 105 nautical miles away from the detonation, received the largest fallout exposure: an estimated dose of 175 r whole-body gamma radiation, beta burns and epilation from contamination of the skin, and slight internal absorption of radioactive material. Another 18 Rongelap people away on a nearby island (Ailingnae), where less fallout occurred, received only about half this exposure. Twenty-eight American servicemen on the island of Rongerik further away received about the same amount of radiation as did the 18 people on Ailingnae (about 70 r). Lastly, 157 Marshallese on Utirik, about 200 miles distant, received only about 14 r whole-body radiation. The fallout was not visible on this island and no skin effects were seen.

The exposed people were evacuated from these islands by plane and ship about two days after the accident and taken to Kwajalein Naval Base about 200 miles to the south, where they received extensive examinations for the following 3 months. In view of the generally negative findings on the American servicemen, they were returned to their duty stations. The Utirik people were repatriated to their home island, where the radioactivity was considered to be low enough for safe habitation. Because Rongelap Atoll was considered to be too highly contaminated, a temporary village was constructed for the Rongelap people on Majuro Atoll several hundred miles to the south, where they remained for the following 3½ years. In July 1957, after careful evaluation of remaining radiological hazards, Rongelap Island was found safe for habitation. A new village was constructed, and the Rongelap people were moved there by Navy ship. The present survey was therefore carried out at Rongelap Island.

SUMMARY OF PAST FINDINGS

Reports have been published on the findings of surveys made at the following times after exposure: initial examinations,[1] 6 months,[2] 1 year,[3] 2 years,[4] and 3 years.[5] The following is a brief summary of these findings.

During the first 24 to 48 hr after exposure, about ⅔ of the Rongelap people experienced anorexia and nausea. A few vomited and had diarrhea. Many also experienced itching and burning of the skin and a few complained of lachrymation and burning of the eyes. Following this, these people remained asymptomatic until about 2 weeks after the accident, when cutaneous lesions and loss of hair developed due largely to beta irradiation of the skin. It was apparent when the people were first examined, a few days after exposure, that the lymphocytes were considerably depressed and that significant doses of radiation had probably been received. In addition to the whole-body dose of radiation and the beta irradiation of the skin, radiochemical analyses of the urine showed that significant amounts of radioactive material had also been absorbed internally. The effects of the radiation can best be summarized under three headings according to the mode of exposure: penetrating irradiation, skin irradiation, and internal irradiation.

Penetrating Irradiation

The changes in the peripheral blood of the more heavily exposed Rongelap people who received 175 r will be reviewed below (see Figures 7, 9, 12 and Tables 3, 4, 5). The changes in the Ailingnae and Utirik groups were similar but less marked. Certain unexplained fluctuations have occured from year to year in the peripheral blood levels of the comparison populations as well as of the exposed groups. Depression of the peripheral blood elements as represented by mean population levels occurred as follows.

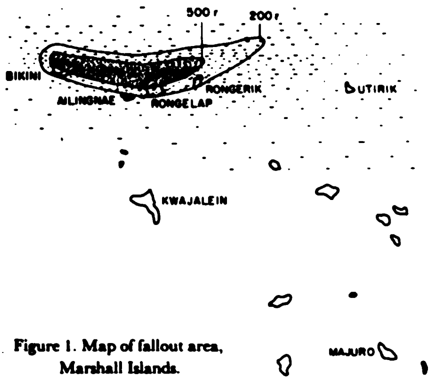

Figure 1. Map of fallout area, Marshall Islands.

Lymphocytes fell promptly and by the third day were about 55% of the control values in adults, and slightly lower in children. There was only slight recovery by six months. At 2 years, although further recovery was evident, the mean values of these cells were still found to be below the comparison population levels (75 to 80%). The 3-year examination showed that the lymphocytes were still somewhat below the level of the unexposed population.

Neutrophil levels fluctuated considerably during the first few weeks but fell gradually to a low of about 50% of control values by the 6th week after exposure. Slow recovery ensued, but at 6 months they were still slightly below the unexposed levels. However, by 1 year post-exposure they had returned to the level of the comparison population and have since remained so.

Platelets fell to about 30% of the unexposed values by the 4th week. By 6 months they had reached 70% of the controls; at 1 year the mean platelet count was still below that of the control population but higher than at the 6-month survey. Although further increases were apparent at the 2- and 3-year examinations, the levels were still below those of the comparison population.

Changes in hematocrit were not remarkable in any of the groups.

Clinical observations revealed no diseases processes or symptoms which could be attributed to radiation effects, aside from skin lesions, loss of hair, and early symptoms. The diseases encountered were no more severe or frequent in the irradiated than in the unirradiated population, even during the period of greatest depression of peripheral blood elements. Epidemics of chicken pox, measles, upper respiratory infections, and gastroenteritis have occurred, but apparently with no greater frequency or severity than in the unexposed populations. Two persons died in the exposed population. One was a 46-yr-old man with hypertensive heart disease which had been present at the time of exposure, who died two years after the accident. The second was a 78-yr-old man who died, three years after exposure, of coronary heart disease complicating diabetes. There was no apparent relationship between these deaths and radiation exposure, and mortality in the exposed group did not appear to have been greater than in the unexposed population.

It is difficult to evaluate the effects of exposure on fertility; however a number of apparently normal babies have been born, and there has been no discernible fall in the birth rate. Several miscarriages developed, but the incidence does not appear to be higher than in the unexposed populations. No opacities of the lens or other eye changes have been found that could be related to radiation. Studies on height and weight and bone age seemed to show a slight degree of retardation in growth and development in the exposed children. However, the small number of children involved, and a later finding that exact ages of some of the children were in doubt, permits no definite statements to be made.

Beta Irradiation of the Skin

No accurate estimate of the radiation dose to the skin could be made. Lesions of the skin and epilation appeared about 2 weeks after exposure, largely on parts of the body not covered by clothing. About 90% of the people had these burns and a smaller number developed spotty epilation. Most of the lesions were superficial; they exhibited pigmentation and dry, scaly desquamation and were associated with little pain. Rapid healing and repigmentation followed. Some lesions were deeper, showed wet desquamation, and were more painful; a few became secondarily infected and had to be treated with antibiotics. Repigmentation of the lesions gradually took place in most instances, and the skin appeared normal within a few weeks. However, in about 15% of the people, deeper lesions, particularly on the dorsum of the feet, continued to show lack of repigmentation with varying degrees of scarring and atrophy of the skin. At 3 years 14 cases continued to show

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some degree of residual skin change largely in the form of pigment aberrations with atrophy and scarring. Numerous histopathological studies have been made, and the changes found have been consistent with radiation damage. However, at no time have changes been observed either grossly or microscopically indicative of malignant or premalignant change.

The spotty epilation on the heads was short-lived, regrowth of hair occurring about 3 months after exposure and complete regrowth of normal hair by 6 months post-exposure. No further evidence of epilation has been seen.

An interesting observation was the appearance of a bluish-brown pigmentation of the semilunar areas of the fingernails and toenails in about 90% of the people beginning about 3 weeks after exposure. By 6 months, however, the pigmentation had largely grown out with the nail and had disappeared in most cases. The cause of this phenomenon has not been explained.

Internal Irradiation

Radiochemical analysis of numerous urine samples of the exposed population showed some degree of internal absorption of radioactive materials, probably brought about largely through eating and drinking contaminated food and water. Calculations of the body burdens of these materials, however, showed that the concentrations were too low to result in any serious effects, and the levels found at 2 and 3 years post-exposure were far below the accepted maximum permissible body level. The results of numerous radiochemical examinations of the urines over the past 4 years, and of gamma spectroscopy over the past 2 years, will be reviewed in greater detail below.

Present Survey

BACKGROUND MATERIAL

Organization

The medical team consisted of 8 physicians, 5 scientists, and 6 technicians from various laboratories in the United States. A Marshallese practitioner and 2 medical technicians from Majuro Atoll assisted the team, as did some of the Rongelap people (see Figure 2).

A group of six scientists from the University of Washington, headed by Dr. E.E. Held, accompanied the team to collect soil, marine, and plant

Figure 2. Medical team personnel.

Figure 3. LST Plumas County beached on Rongelap Island.

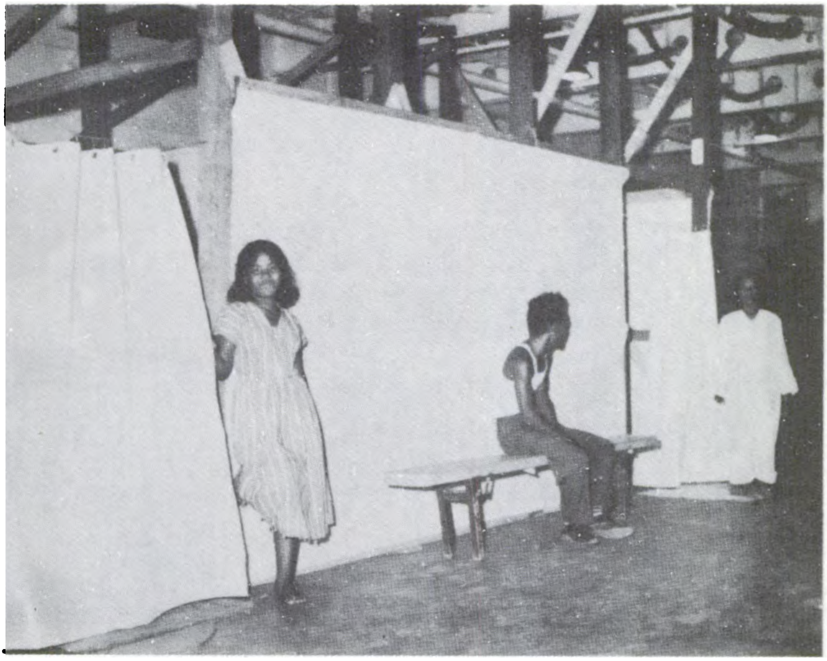

Figure 4. Personnel decontamination station aboard LST.

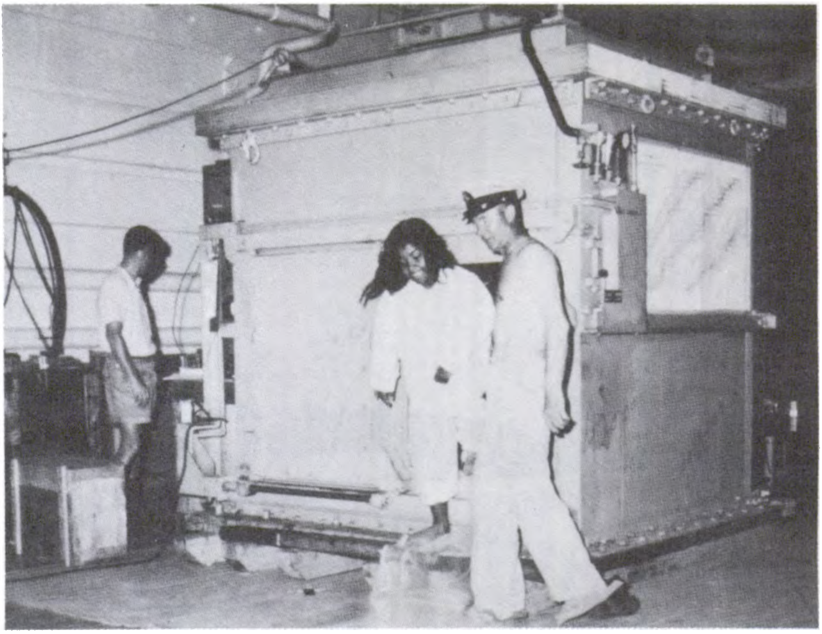

Figure 5. Steel room used for whole-body gamma spectroscopy.

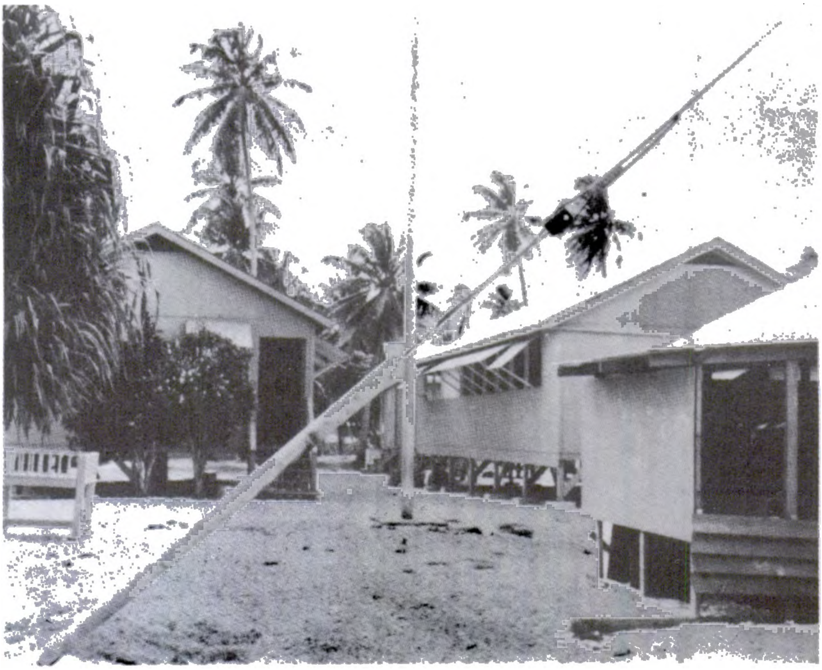

Figure 6. Dispensary and examination buildings, Rongelap Island.

samples for radiochemical analysis. These studies are not yet complete and have not been included in this report.

The Navy kindly furnished a ship for the expedition, an LST, the USS Plumas County (Figure 3). The LST picked up medical equipment for the survey, including a 21-ton steel room for carrying out whole-body counts on the Rongelap people, about the middle of February at Hawaii and proceeded to Kwajalein. The medical team staged in Hawaii and flew via military air transportation to Kwajalein, boarded the LST, and proceeded to Rongelap Atoll. At Rongelap the LST was beached for easy accessibility to Rongelap village.

The 21-ton steel room, constructed at Brookhaven National Laboratory for use in whole-body gamma spectroscopy on the Marshallese in this and future surveys, measured 5 ft 8 in. by 5 ft 8 in. by 6 ft 6¼ in., with 4-in.-thick walls and ceiling and a 2-in.-thick floor. The room had been set up in the tank deck of the LST along with two 100-channel analyzers, a 5-in. crystal, and other accessory electronics equipment. A dressing room and shower facility had also been constructed on the tank deck for decontamination of personnel prior to whole-body counts. (See Figures 4 and 5.)

The histories were taken, and the physical and laboratory examinations were carried out at Rongelap village in the dispensary, school building, and council house (see Figure 6). The examinations lasted 3 weeks.

Difficulties Associated with the Examinations

Several difficulties associated with carrying out the examinations as well as interpreting the findings should be pointed out.

1) The language barrier made examinations difficult since very little English is spoken by the Marshallese. However, there were sufficient English-speaking Marshallese to assist the medical team in most instances in carrying out the examinations.

2) The lack of vital statistics or demographic data on the Marshallese imposed a serious difficulty in interpretation and evaluation of the medical data. Records of births, deaths, etc., have been made by the health aides or magistrates of the villages and supposedly forwarded to the district administrator; however, such records have been poorly kept or lost in most instances and thus vital statistics are practically nonexistent. Trust Territory officials are now attempting to assemble such data.

3) It is unfortunate that many of the Marshallese, particularly in the older age group, are uncertain of their exact ages, largely because few written records of birth are maintained.

Comparison Populations

During the first 2 years, two separate groups of Marshallese people were used for comparison, each of comparable size to the exposed Rongelap group and matched in age and sex. However, this population was found to be unstable, with a large attrition rate over the 2 years, which made it unsatisfactory. At the time of the 3-year survey, it was found that during the preceding 12 months the Rongelap population at Majuro Atoll had doubled because of the influx of relatives who had come back from other islands to live with them. These people had been away from Rongelap Atoll at the time of the accidental exposure. This group matched reasonably well for age and sex and was of comparable size; moreover, since these people were of the same stock genetically, they proved to be uniquely appropriate to serve as a comparison population. This group was therefore used at the 3-year examination as a control and again during the present survey.

PROCEDURES

History and Physical Examinations

Histories were taken by a Marshallese practitioner with particular emphasis on the interval history during the past year.

Complete physical examinations were carried out including examinations of the children for growth and development, anthropometric measurements, and x-ray examinations of the left wrist and hand for bone development studies; special examinations of the skin with color photography for selected lesions; ophthalmological studies including slit-lamp observations, visual acuity, and accommodation; and EGC and x-ray examinations as deemed necessary.

Laboratory Examinations

Hematological examinations included three complete blood analyses with WBC, differential, platelet counts (phase microscopy), and hematocrit (microhematocrit method) done at about weekly intervals.

The following examinations of the blood were made to determine genetically determined traits.

These studies were of interest in evaluating the homogeneity of the Rongelap people and learning something of their anthropological background.

Blood grouping studies. Studies of the blood groupings and gene distributions in the blood of 129 Marshallese were carried out by Dr. L.N. Sussman of the Beth Israel Hospital, New York City. The following systems were studied: ABO, MN, Rh-Hr, and Duffy, Kell, and Diego factors.

Haptoglobin studies. The method of Smithies was used, in which electrophoresis is carried out with a starch gel slab as supporting medium.[6] This analysis was made on 126 Marshallese blood samples by Dr. B.S. Blumberg of the National Institutes of Health, Bethesda, Maryland.

Hemoglobin types. The determination of hemoglobin types was made on 45 Marshallese blood samples by the method of Smithies[6] (starch gel zone electrophoresis). These studies were carried out by Dr. R.L. Engle, Jr. and Dr. G. Castillo of the Cornell University Medical Center, New York, N.Y.

Plasma proteins. Plasma protein determinations were carried out on all sera by the proteinometer technique.

Thyroid metabolism. In view of the exposure of the thyroid glands to radiation from the internally absorbed radionuclides, the metabolic state of the thyroid gland was of interest. These studies were made by Dr. J.E. Rall at the National Institutes of Health, Bethesda, Maryland. Protein-bound iodine determinations were carried out on 36 people in the exposed group and 24 in the comparison population. Butanol-extractable iodine content was measured in three people in each group, and thyroxine-binding proteins were determined in 12 persons in the comparison population.[7]

Serum vitamin B_{12} concentrations. In view of the general tendency to anemia in the population, serum vitamin B_{12} contents were measured to see whether they could be related to anemia. These determinations were carried out on the sera of 44 exposed Marshallese and 58 unexposed by Dr. D.W. Watkin of the National Cancer Institute, National Institutes of Health, Bethesda, Maryland. The method used was a modification of the USP XV *Lactobacillus leichmannii* method developed specifically for vitamin B_{12} assay in serum.[8]

Intestinal parasite survey. The generally high eosinophil counts and tendency to low hematocrits noted in both the exposed and unexposed Rongelap people led to an intestinal parasite survey to see whether parasitism might be responsible for these findings. Because of the generally accepted view that blood pictures of anemia and eosinophilia are more likely to be associated with helminthic rather than with protozoan infections of the intestinal tract, the methods used were directed primarily to detecting the former. The Beaver method of egg counting[9] and formalin-ether concentration[10] was used to obtain quantitative information on helminth infections. This is a simple, direct technique which is also useful in revealing protozoan infections, particularly when trophozoites are present. In addition, all stools were concentrated by the formalin-ether method to pick up infections too light to be detected by direct examination. One stool specimen per person was examined in each of 69 exposed persons and 112 unexposed. Specimens were brought to the laboratory shortly after being passed, and were generally examined within 1 hr. The methods used probably revealed ⅓ to ½ of the protozoan infections and perhaps 80% of the helminth infections likely to be found in these individuals had they been subjected to repeated examinations.

Serum and food sodium and potassium determinations. Because the Marshallese seem to have generally lower blood pressures and in view of the possibility that salt intake bears a causal relationship to essential hypertension in humans,[11,12] correlations between salt intake and incidence of hypertension were investigated by Dr. L.K. Dahl of Brookhaven National Laboratory. A morning sample (before breakfast) of urine was obtained on 13 exposed and 14 unexposed persons and analyzed for sodium and potassium level by flame spectrophotometry. A sample prepared meal was also obtained for similar analysis of the several items.

Determination of Body Burdens of Radionuclides

Radiochemical urine analyses. Urine samples, 24-hr as well as cumulative, were collected from 15 Rongelap people for radiochemical analyses carried out under the direction of Maj. K. Woodward and Col. J. Hartgering at the Walter Reed Army Institute of Research, Washington, D.C.

Whole-body gamma-ray spectroscopy. During this survey about 200 people were examined in the whole-body counter (21-ton steel room constructed at Brookhaven National Laboratory and carried out to the Islands) for body levels of gamma emitting nuclides. Unfortunately, the

data on these counts as well as considerable medical equipment were lost in the Pacific Ocean when the cargo had to be jettisoned from a plane which developed engine trouble. A return trip to Rongelap Island was made two months later (May 1958), and about 100 Rongelap people were again counted in the steel room. Details of the procedures used and the results will be described below.

FINDINGS

Living Conditions

During the past year the Rongelap inhabitants have become well adjusted to life in their new village, which was completely rebuilt, with well constructed houses far superior to the old ones. An interesting sidelight is that some of the people, particularly the older ones, prefer to live beneath their houses, probably because it is cooler and they prefer not to climb the steps.

During the 8 months since the people returned, copra production was being satisfactorily re-established, but it had not reached full capacity. The establishment of an agricultural program was proceeding disappointingly slowly. At this writing it is understood that the Trust Territory is sending a full-time agriculturist to implement this program.

Adequate water is available on Rongelap from the concrete water catchment cisterns from the roofs of nearly all the houses. Flies are quite prevalent. Most of the people still cook outdoors rather than in the screened cook-houses built for them. Scraps of food around the cooking area probably predispose toward flies. The screened-in latrines are a big improvement, and it is hoped that the children will make greater use of them. This point has been emphasized to the people in order that intestinal parasites may be better controlled. The island is heavily infested with rats and some sort of extermination program is indicated.

The diet is extremely limited in variety, although caloric intake appears to be adequate. The chief source of carbohydrate is rice and a small amount of flour. Protein is derived largely from fish with an occasional supplement of canned meat. The fat intake is mostly from coconut meat. Vitamins are obtained mainly from coconuts, pandanus (when available), and fish. In view of the importance of diet in relation to certain puzzling clinical laboratory findings, the following more detailed information is presented.

Fish is the main source of protein. It is eaten fresh, dried, or salted, several times weekly and frequently daily. A great deal more is eaten fresh than otherwise. The liver is included. Among ***canned meats***, corned beef is well liked as well as salmon and sardines. About one can (perhaps two) is eaten weekly per person. ***Other meats*** include pigs and chickens which run loose on the island and are eaten on rare occasions. Clams (particularly the giant clams) are eaten when they can be found; however, they are not plentiful now. Land crabs are considered a delicacy, but eating them is forbidden at this time because of their high Sr^{90} level. (This is the only forbidden dietary item.)

Local plant products. Coconuts are an important item of the diet, eaten green or ripe. About three green coconuts per day are consumed per person, both milk and meat. Ripe coconut is eaten with meals either as such or grated onto rice and fish. ***Pandanus*** is available during the summer and fall. The fruit is eaten raw by sucking the sweet juice from the fibrous segments. The juice is also squeezed out and used to flavor arrow root flour and to make a candy known as "jenkum." This fruit is probably a major source of vitamin A and possibly C. ***Arrowroot*** is grated to form a starchy flour, which is cooked into a mushy, tapioca-like material. It is available principally in the winter months. ***Breadfruit***, a starchy fruit, is not abundant on Rongelap but is eaten when available. ***Rice, salt, sugar, flour, tea,*** and ***canned meats*** are imported. Rice is a mainstay eaten three times a day. Sugar is used to sweeten tea. A little salt is used in cooking rice and bread, but is usually in short supply and is rarely used on prepared food. Bread and pancakes are frequently eaten.

Interval Medical History

The general health of the Rongelapese has been good during this past year. Six children (4 exposed and 2 unexposed) presumably had infectious hepatitis during November and December 1957. No other major epidemics or diseases were reported. Abdominal pain and diarrhea were among the commonest complaints, and were probably associated with the eating of food kept several days without refrigeration. The large number of flies may also play a part in the prevalence of this condition. A complaint of night blindness of several months duration among 10 children and 1 adult was investigated and is reported below. Common colds, fungus infections of the skin, and impetigo

were also common complaints for which the health aide was consulted.

During the past year healthy babies were born to 4 irradiated women and 6 unexposed women. The exposed and unexposed groups each contain 19 women of child-bearing age (15 to 44 years). Three miscarriages occurred in the exposed women, two at 3 months and one at about 6 months. In all three cases this was the second miscarriage since exposure. However, two of the women have had one normal pregnancy since the accident. One of the unexposed women had a miscarriage, and another had a full-term baby that died within a month, apparently of diarrhea of infancy. (Between the March survey and the return survey in May 1958, one exposed woman had a full-term baby that died shortly after birth of unknown cause.)

One death, presumably due to coronary thrombosis, occurred in July 1957, that of a 78-yr-old diabetic male. No autopsy was obtained. One unexposed 65-yr-old male died in January 1958, presumably of arteriosclerosis and senility. No autopsy was obtained.

Physical Examinations

Examinations showed the general physical condition of the people to be satisfactory. Grossly, nutritional status was also satisfactory, in spite of the dietary restrictions referred to above. However, 6 children (all in the unexposed group) showed mild to moderate degrees of hemeralopia when put through an obstacle course test at night. All were treated with vitamin A and recovered rapidly. This evidence of mild vitamin A deficiency is understandable after study of their diet. At that time of the year pandanus was not ripe and other sources of vitamin A were scarce.

Table 1 lists the major diseases noted in the exposed and unexposed people. The diseases found were present with about the same frequency in the unexposed and exposed groups. No malignant conditions were noted.

Physical examination of the children revealed few major medical disorders in either the exposed or unexposed groups. One exposed child had inactive rheumatic heart disease with evidence of polyvalvular involvement (reported previously). He showed no further evidence of decompensation such as had occurred 3 years previously and was able to keep up with other children in their play. Extensive molluscum contagiosum and superficial pustules on the legs were common. An occasional child had palpable cervical nodes, but tonsilar hypertrophy was uncommon. Xeroderma, cheilosis, and glossitis were not seen.

In the exposed adults, one case of auricular fibrillation of several years standing in a 50-yr-old male continued asymptomatic. The case of leprosy showed no progression of the lesions of the hands

Table 1

Incidence of Various Disease States Among the Marshallese (52 exposed adults and 55 unexposed adults examined)

	Exposed	Unexposed
CONGENITAL ANOMALIES		
Short 5th finger	1	2
Prominent ulnar styloid process	3	2
Congenital dislocated hip	0	1
Heberden's nodes	1	1
Adrenogenital syndrome	0	1
Pilonidal sinus	2	0
Hernia, umbilical	0	0
Congenital nystagmus	0	1
Congenital facial asymmetry	0	1
OTHER ABNORMALITIES FOUND		
Cheilosis	1	0
Tinea versicolor	4	7
Kyphoscoliosis	7	3
Impetigo and ecthyma	1	0
Healed yaws	1	1
Bronchitis	9	5
Hypertension	5	6
Arteriosclerosis, peripheral	2	1
Osteoarthritis	2	4
Obesity	2	2
Chronic cervicitis	0	2
Cystocele and rectocele	2	2
Emphysema	4	0
Uterine fibroids	0	2
Goiter	0	2
Hemorrhoids	0	1
Hepatosplenomegaly	1	0
Abnormal knee-jerks	0	1
Keloid	1	1
Leprosy	1	0
Functional heart disease	1	0
Rheumatoid arthritis	0	1
Ovarian cyst	0	1
Anal fistula	0	1
Dupuytren's contracture	0	1
Senile vaginitis	0	2
Hallux valgus	0	1
Leontiasis osseum	0	1
Urethral caruncle	1	0

and feet. Marked improvement was noted in the case of an 80-yr-old man who had suffered a cerebral accident 2 years previously; much of the unilateral paralysis had disappeared. Three other aged exposed people, two females, one supposedly 101 years of age and one 75, and one male 79, were obviously becoming more infirm. They rarely left the seclusion of the mats beneath their houses. Only one unexposed person was in this same age range, a male aged 84 who was still able to move about fairly well.

In April 1958, after the March survey, a death occurred in a 36-yr-old male from the Ailingnae group, which had received about 69 r of gamma irradiation from the fallout in 1954. He had complained in March of epigastric pain, anorexia, and loss of vigor. Physical examination at that time was essentially negative except for epigastric tenderness. A tentative diagnosis of peptic ulcer was made, although it could not be substantiated since x-rays were not available. He improved on an ulcer diet including canned milk. About 3 weeks later, after the survey team had left, he became acutely ill and was transferred to the Naval Hospital at Kwajalein, where he died the following day. The entire skin and mucous membranes of the mouth were covered with uniocular vesicles and bullae. Autopsy revealed acute bilateral pneumonia of unknown origin and passive congestion of the liver. A diagnosis of varicella was made. Microscopic examination of the skin lesions showed inclusion bodies typical of varicella.*

The striking thing about the physical examinations in both the exposed and unexposed people was the relative paucity of findings associated with degenerative diseases. While the group under observation is too small to permit any valid statistical analysis, the clinical impression was that diseases such as atherosclerosis and hyptertension were considerably less common and of lesser severity than in a comparable group of our population. Among the 114 people 50 years old or less, none had a blood pressure greater than 140/90. Among the 23 persons older than 50 years, 6 had pressures ranging from 160 to 220 systolic and 90 to 110 diastolic, and 2 had systolic elevations of 160 to 170 but diastolic pressures of 75 to 80. The groups were too small for these findings to be evaluated relative to American statistics, but it can be said that the blood pressures do not exceed those commonly found and probably are lower.

There was a general feeling that conditions like hernia, varicose veins, hemorrhoids, and vaginal prolapse were much less common than one might anticipate in examining a random group of people of similar age in our society. One interesting finding was a relatively high incidence of kyphosis. While this is common in older people in our own population, it was particularly striking in the Marshallese, because it appeared to be localized to the lower thoracic and lumbar region. Fungus infections of the skin, particularly Tenia versicolor, were widespread.

Growth and Development Studies

Cross sectional data on height and weight and bone age determinations for the 2- and 3-year surveys gave an impression of lag in growth and development in the exposed children compared with unexposed children of the same age. However, in an attempt to obtain more accurate birth dates of the children for the 4-year survey, the ages of some of the children, previously thought to be well established, were found to be questionable. The absence of recorded birth information seriously complicates the determination of the accuracy of given chronological ages and dates of birth. More definitive evaluation of data will be possible when verification of birth dates is completed. Detailed geneological and biological histories are being compiled to establish the most probable birth date of each child. (Unfortunately, the 1958 roentgenograms of the wrist and knee, intended for assessment of osseous maturation, were lost at sea.)

In addition to cross sectional studies, longitudinal studies of incremental growth data and bone maturation studies over the period since exposure will be undertaken when the ages of the children are better established.

Ophthalmological Examinations

Table 2 shows the major ophthalmological findings. Generally the Rongelap people, exposed and unexposed, showed superior vision and accommodation. The majority of disorders were found in the conjunctiva, cornea, and lens. Irritation of the eyes from bright tropical sunlight and exposure to coral dust probably play a part in the high incidence of conjunctival and corneal defects.

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*We are grateful to Capt. B.E. Bassham, (MC) USN, for doing the autopsy, and to Dr. S.W. Lippincott and Dr. H.A. Johnson of Brookhaven National Laboratory for the histological examination.

Table 2

Ophthalmological Findings (% incidence)

	Exposed	Unexposed
Pterygium	30.5	16.3
Pinguecula	24.4	15.3
Corneal pigment	6.1	4.8
Corneal scars	9.8	8.6
Arcus senilis	29.2	12.5
Dacryocystitis	1.2	0.0
Phthisis bulbi	3.6	1.0
Nystagmus	0.0	1.0
Pannus	1.2	0.0
Strabismus	7.3	1.0
Molluscum contageosum	3.6	3.8
Argyll-Robertson pupil	1.2	0.0
Keratitic precipitates	1.2	0.0
Cataracts	12.1	0.0
Aphakia	6.1	2.9
Vitreous opacities	8.5	0.0
Retinal arteriosclerosis	10.7	9.6
Choroidal scars	4.8	1.9
Macular degeneration	2.4	0.0
Drüsen	1.2	2.4
Congenital anomalies	3.6	1.0
Macrocornea	15.9	14.4

Slit-lamp observations revealed no opacities of the lens in the exposed people like those seen in the irradiated Japanese.[13,14] Also, no differences between the exposed and the unexposed groups were noted in visual acuity or accommodation.[15] A high incidence of such conditions as pinguecula and pterygium has been noted in the exposed group. This finding may have no significance, but it is not known whether the exposure of the eyes to beta irradiation in 1954 from fallout could have played an etiological role.

It is of interest that no cases of glaucoma were noted. The incidence of myopia was very low, as was the incidence of retinal arteriosclerosis, squint, and deficiency in color vision. Of interest was the finding of a large number of adults and children with large corneas, and anomalies of the retinal vascular patterns.

Examination of the Skin

Twelve cases continued to show residual evidence of beta lesions of the skin. These were for the most part mild and consisted of slight atrophy and pigment aberration. A few lesions showed scarring and atrophy with slight adhesion of the skin to subcutaneous tissues, and lack of pigment formation. However, improvement was noted in most lesions and in no case was there any aggravation of the lesion or tendency to develop chronic radiation dermatitis, or any change that appeared to be malignant or premalignant. In view of the generally favorable progress of the lesions, no biopsies for microscopic study were taken on this survey.

Laboratory Examinations

Hematological – Routine. The basic hematological data are presented in Tables 3 to 6. The mean blood counts of the exposed people and of the various comparison populations are shown for the 4-year period since March 1954. In Figure 7 are plotted the mean of two separate absolute blood counts on the exposed groups carried out during the 4-year survey, along with mean levels for other post-irradiation intervals; the open circles represent the mean values for the comparison population. The blood data have been classified as in the past according to age and sex.* The following represent the findings on the more heavily exposed Rongelap group compared to those on the unexposed Rongelap people.

WBC. The mean WBC was slightly higher in both exposed and unexposed groups in both the <5 and >5 year age groups compared with the levels a year ago (see Table 3 and Figure 7). The exposed level is about the same as the control level.

The ***neutrophils*** showed a further slight decrease in the exposed group since a year ago (Table 3, Figure 7). These counts in most cases reached a peak at 1 to 2 years post-exposure and declined during the following 2 years. In fact the counts this year are the lowest since the maximum depression occurred at 6 weeks post-exposure. In spite of this observation, the counts show little difference (5% less) from those in the unexposed group. A scattergram (Figure 8) age distribution

	Sex	Age, yr	Rongelap	Ailingnae	Unexposed Rongelap
*Leukocytes:	both	<5	8	2	5
	both	>5	56	16	80
Platelets:	M	<10	9	2	10
	M	>10	22	5	40
	F	all ages	33	11	34
Hematocrits:	M	<15	12	2	17
	M	>15	19	5	34
	F	all ages	33	11	34

of the counts compared with the mean curve of the unexposed neutrophil counts shows that children about 12 years of age and below have more counts below than above the mean curve of the unexposed children of the same age range. However, above this age the distribution of counts is about the same.

The mean of the ***lymphocyte counts*** shows an increase since last year's counts of 33% in the exposed groups (Figure 9). It is this increase in lymphocytes that accounts for the rise in the total white count noted above. The lymphocytes in the exposed group are at the highest point since exposure. However, a scattergram (Figure 10) shows that more of the counts in the exposed group are below than above the mean unexposed curve. An accumulative percentage distribution of the counts (Figure 11) shows the exposed curve still to be slightly displaced to the left.

Eosinophil and ***monocyte*** and ***basophil*** counts are about the same in the exposed as in the unexposed groups. The eosinophil counts were quite high in both exposed and comparison populations, but were about the same in the two groups. In their differential counts, 45% of the exposed and 55% of the unexposed had eosinophils of 5% or greater.

Mean ***platelet counts*** have shown further recovery this year in both sexes of the exposed group compared with last year's results (Figure 12). As

Table 3

Rongelap Group and Control Mean Blood Counts by Day and by Age

	WBC ($\times 10^{-3}$)		Neutrophils ($\times 10^{-3}$)		Lymphocytes ($\times 10^{-3}$)		Platelets ($\times 10^{-4}$)				Monocytes ($\times 10^{-2}$)		Eosinophils ($\times 10^{-2}$)	
Postexposure day	<5	>5	<5	>5	<5	>5	Male <10	Male >10	Female all ages	Total group	<5	>5	<5	>5
3	9.0	8.2	6.4	4.7	1.8	2.2	—	—	—	—	0.8	0.3	0.1	0.7
7	4.9	6.2	—	—	—	—	—	—	—	—	—	—	—	—
10	6.6	7.1	3.5	4.5	2.6	2.1	28.2	22.7	24.9	24.8	2.9	1.7	1.6	1.6
12	5.9	6.3	3.5	3.9	2.1	1.7	—	—	—	—	4.2	5.4	1.9	1.9
15	5.9	6.5	3.2	4.1	2.4	1.9	27.1	21.3	21.7	22.5	3.0	2.3	1.1	1.3
18	6.7	7.2	3.4	4.7	2.4	2.1	21.8	19.1	21.8	21.0	2.7	1.7	3.5	1.6
22	7.0	7.4	4.3	5.0	2.6	2.1	16.8	14.6	15.2	15.3	1.9	2.0	2.3	1.8
26	5.7	6.1	3.0	3.9	2.3	1.8	13.2	12.9	10.9	11.9	1.9	1.6	1.8	1.3
30	7.6	7.8	4.0	5.3	3.2	2.1	14.1	12.3	11.8	12.3	1.5	0.9	3.4	2.2
33	6.5	6.2	3.1	3.8	3.2	2.0	17.9	16.6	15.1	16.0	1.7	1.6	2.6	2.2
39	5.7	5.5	3.0	3.3	2.6	2.0	25.5	22.0	22.4	22.8	0.9	0.9	0.5	1.0
43	5.2	5.2	2.0	2.6	2.9	2.3	26.8	20.9	23.2	23.2	1.1	1.1	1.4	0.8
47	5.9	5.8	2.6	3.3	3.1	2.4	24.6	20.6	23.9	23.1	1.0	1.0	1.1	0.5
51	6.7	5.6	2.6	3.5	3.4	2.1	22.1	17.5	21.2	20.3	2.5	1.6	0.8	0.7
56	7.0	6.0	3.5	3.5	3.7	2.4	—	—	—	—	1.7	1.2	—	—
63	7.7	6.0	3.9	3.6	3.7	2.3	23.1	18.2	20.2	20.1	0.5	0.9	0.3	0.6
70	7.6	6.5	3.8	4.0	3.3	2.2	—	—	—	—	—	—	3.4	1.9
74	—	—	—	—	—	—	26.2	21.7	24.7	24.1	—	—	—	—
6-mo survey	8.5	6.6	4.6	4.2	3.6	2.2	24.4	20.3	23.2	22.6	1.4	1.1	2.5	1.6
1-yr survey	10.1	8.1	4.7	4.8	4.6	2.8	26.6	19.5	27.6	24.9	0.7	1.3	6.7	2.8
2-yr survey	11.8	8.6	5.9	4.8	4.7	3.1	30.0	21.4	25.5	24.7	2.7	1.5	9.6	5.3
3-yr survey	8.6	6.9	4.1	3.7	3.7	2.7	32.0	22.1	28.1	—	1.2	0.7	6.4	4.5
4-yr survey	8.9	7.5	3.3	3.4	4.6	3.6	32.5	27.1	30.8	—	1.5	1.1	7.9	4.0
Majuro controls	13.2	9.7	4.8	4.8	7.4	4.1	41.2	25.8	36.5	33.4	2.0	2.0	9.5	4.7
Rita controls, 6 mo	10.7	7.6	5.4	5.2	4.7	3.7	35.0	27.3	30.9	30.4	1.9	1.7	4.2	4.8
Rita controls, 1 yr	—	—	—	—	—	—	37.5	24.5	29.4*	27.6	—	—	—	—
Rita controls, 2 yr	14.0	8.9	7.0	4.4	5.6	3.6	35.5	24.2	31.2	29.5	1.4	1.5	12.8	6.6
Rongelap controls, 3 yr	9.8	6.9	4.0	3.4	4.7	2.9	32.6	26.9	30.0	—	1.4	0.7	6.2	4.0
Rongelap controls, 4 yr	11.2	8.0	4.0	3.6	6.2	3.7	38.8	30.7	34.0	—	2.3	1.1	7.0	4.5

*Excluding pregnancy.

with the lymphocytes, the platelet counts are the highest yet attained since exposure. However, the unexposed group also showed an increase in mean platelet count compared with last year; but the exposed group levels are still significantly below the unexposed (males, <10, −16%; >10, −11%; and females, all ages, −9%). This is also borne out by the following findings: (1) 22% of the exposed group have levels below 250,000 compared with only 7% in the unexposed people; (2) the scattergrams (Figures 13 and 14) show more counts below than above the unexposed mean curve in both sexes; and (3) the accumulative percentage distribution curve (Figure 15) is displaced to the left of the unexposed curve.

Erythropoietic function as evidenced by hematocrit levels shows little difference between the exposed and the unexposed groups, and neither group shows significant change since last year. The exposed males >15 years of age continue to show slightly lower hematocrit values than do unexposed males of the same age (see Table 6). However, the other blood elements in this group of males do not appear lower than in the unexposed group. A general anemic tendency in the Marshallese (combined exposed and unexposed groups) is borne out by the finding that 78% of the females have hematocrits of 36% or less and 54% of the males have hematocrits of 38% or lower.

Counts in the Ailingnae group. From Table 4 it can be seen that the counts in the 18 people of this group averaged nearly the same for the various blood elements as did the counts in the more heavily exposed group. Lymphocyte levels and platelet levels in the males were slightly lower, however. These same differences were noted at the time of the 3-year survey.

Individual counts. In reviewing the individual peripheral blood counts, lower levels were found in more exposed individuals than in the unexposed group. Those showing generally lower counts in the two groups are listed in Table 7.

Table 4

Ailingnae Group and Control Mean Blood Counts by Day and by Age

	WBC ($\times 10^3$)		Neutrophils ($\times 10^3$)		Lymphocytes ($\times 10^3$)		Platelets ($\times 10^4$)				Monocytes ($\times 10^2$)		Eosinophils ($\times 10^2$)	
Postexposure day	<5	>5	<5	>5	<5	>5	Male <10	Male >10	Female all ages	Total group	<5	>5	<5	>5
3	6.0	7.0	3.0	5.0	2.8	2.2	—	—	—	—	0.8	1.6	0.5	0.4
7	5.5	6.8	—	—	—	—	—	—	—	—	—	—	—	—
10	6.3	7.3	4.2	4.2	1.9	2.2	22.5	22.6	20.9	21.5	3.8	2.1	2.6	1.6
12	6.3	7.6	1.8	4.7	3.1	2.2	—	—	—	—	3.4	5.8	4.4	2.6
15	7.1	7.0	2.3	4.5	4.2	2.2	29.0	20.2	24.6	23.9	3.7	2.6	2.3	1.4
18	6.8	7.8	2.9	5.0	3.5	2.4	27.5	21.7	24.9	24.3	2.3	1.5	3.2	2.3
22	8.9	8.7	5.3	5.4	2.7	2.9	23.5	17.0	22.9	21.3	1.5	2.4	5.8	2.4
26	8.4	7.0	4.8	4.4	3.2	2.2	20.0	13.8	17.4	16.7	2.3	2.4	0.6	1.6
30	9.6	8.6	5.3	6.2	3.7	2.0	19.5	12.8	18.2	16.8	1.9	1.9	4.1	2.0
33	7.7	7.8	3.3	5.2	3.5	2.2	24.0	15.8	22.7	17.6	2.8	2.2	6.0	1.9
39	7.5	6.2	2.9	4.2	4.7	1.9	26.5	20.8	27.0	25.2	1.1	1.7	2.7	1.6
43	6.9	6.5	2.7	3.6	3.9	2.7	28.0	19.6	25.3	24.0	0.6	1.4	2.8	0.6
47	7.3	6.7	3.5	3.8	3.4	2.7	27.0	20.0	26.1	24.5	2.2	1.9	1.5	0.7
51	8.4	6.3	3.8	3.6	4.0	2.2	32.0	18.2	25.0	23.9	2.7	2.8	2.2	1.0
54	4.6	6.3	2.8	3.5	3.2	2.5	37.0	19.8	23.8	24.2	1.5	1.9	1.8	0.8
6-mo survey	7.7	6.5	4.8	3.9	2.7	2.2	25.2	19.2	23.9	22.7	1.1	1.4	1.5	2.2
1-yr survey	11.1	7.8	4.2	4.7	6.5	5.6	38.7	21.4	28.3	27.5	1.0	1.1	1.7	2.2
2-yr survey	11.0	9.1	4.9	5.1	4.8	3.2	51.2	17.4	26.4	26.7	3.6	1.4	9.6	6.4
3-yr survey	12.1	7.0	5.5	3.9	5.6	2.6	40.8	22.4	31.2	—	3.0	0.7	5.3	3.7
4-yr survey	11.5	7.5	2.8	3.7	7.0	3.3	33.2	24.7	33.6	—	2.2	1.1	12.6	4.2
Majuro controls	13.2	9.7	4.8	4.8	7.4	4.1	41.2	25.8	36.5	33.4	2.0	2.0	9.5	4.7
Rita controls, 2 yr	14.1	8.9	7.0	4.4	5.6	3.6	35.5	24.2	31.2	29.5	1.4	1.5	12.8	6.6
Rongelap controls, 3 yr	9.8	6.9	4.0	3.4	4.7	2.9	32.6	26.9	30.0	—	1.4	0.7	6.2	4.0
Rongelap controls, 4 yr	11.2	8.0	4.0	3.6	6.2	3.7	38.8	30.7	34.0	—	2.3	1.1	7.0	4.5

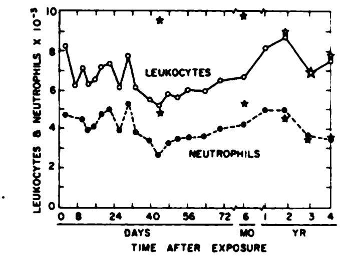

Figure 7. Mean neutrophil and white blood cell count of exposed Rongelap people from exposure through 4 years post-exposure. Stars represent mean value of control population.

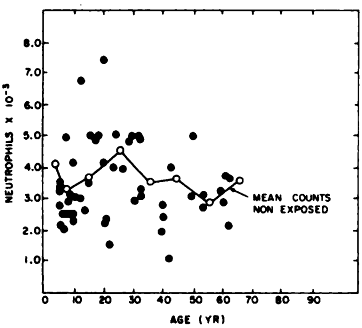

Figure 8. Neutrophil scattergram of individual counts plotted against age; Rongelap, age >5, 4 years post-exposure. Open circles represent mean counts of comparison population.

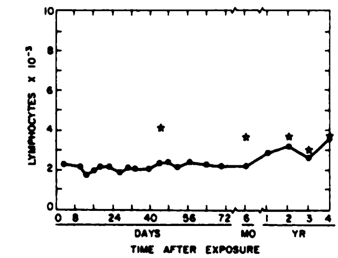

Figure 9. Mean lymphocyte values for exposed Rongelap people from exposure through 4 years post-exposure. Stars represent mean values of control population.

Table 5

Hematocrits

	Rongelap			Ailingnae		
Postexposure day	Male <15	Male >15	Female all ages	Male <15	Male >15	Female all ages
22	37.5	43.9	39.0	37.5	43.7	39.2
26	36.3	41.6	37.5	36.5	43.2	36.8
30	37.9	42.2	37.1	36.0	44.6	36.7
33	37.4	42.2	36.8	35.5	43.8	37.3
39	37.8	42.4	37.4	35.0	45.6	37.4
43	37.3	41.8	37.6	36.0	45.2	36.8
47	39.0	43.4	38.3	—	46.5	40.2
6-mo survey	38.0	41.7	38.2	37.5	40.1	37.3
1-yr survey	37.5	41.1	36.9	33.0	44.6	36.2
2-yr survey	38.7	41.2	38.1	35.7	44.4	37.5
3-yr survey	35.6	38.7	35.4	37.5	40.6	36.5
4-yr survey	35.6	41.0	35.8	36.1	43.1	35.7
Majuro controls	39.6	46.0	39.9	39.6	46.0	39.9
2-yr controls	38.9	42.1	39.8	38.9	42.1	39.8
3-yr controls	35.6	41.0	35.9	35.6	41.0	35.9
4-yr controls	35.5	42.8	35.1	35.5	42.8	35.1

Table 6

Mean Blood Count by Age and Sex for the Exposed and Control Groups, 1958

	Rongelap	Ailingnae	Unexposed Rongelap
WBC ($\times 10^{-3}$)			
4 - 5	8.9 (7)* ±1.4**	11.5 (1)	11.2 (4) ±1.4
>5	7.5 (48) ±1.6	7.5 (15) ±1.8	8.0 (68) ±1.8
Neutro ($\times 10^{-3}$)			
4 - 5	3.3 ±0.9	2.8	4.0 ±1.0
>5	3.4 ±1.2	3.7 ±1.0	3.6 ±1.2
Lymph ($\times 10^{-3}$)			
4 - 5	4.6 ±1.2	7.0	6.2 ±1.0
>5	3.6 ±1.1	3.3 ±1.2	3.7 ±1.0
Mono ($\times 10^{-2}$)			
4 - 5	1.5 ±1.0	2.2	2.3 ±1.8
>5	1.1 ±0.6	1.1 ±0.9	1.1 ±0.8
Eosin ($\times 10^{-2}$)			
4 - 5	7.9 ±5.2	12.6	7.0 ±3.7
>5	4.0 ±2.1	4.2 ±4.7	4.5 ±3.4
Platelets ($\times 10^{-4}$)			
Males 4 - 10	32.5 (8) ±8.6	33.2 (2)	38.8 (7) ±6.6
>10	27.1 (18) ±5.8	24.7 (4) ±2.3	30.7 (33) ±5.4
Females > 3	30.8 (29) ±7.0	33.6 (10) ±7.4	34.0 (32) ±5.6
Hematocrit			
Males 3 - 15	35.6 (11) ±1.5	36.1 (2)	35.5 (14) ±1.8
>15	41.0 (15) ±2.4	43.1 (4) ±2.8	42.8 (26) ±2.8
Females > 4	35.8 (29) ±1.5	35.7 (10) ±3.8	35.1 (32) ±2.1

*Number of individuals.
**Standard deviation.

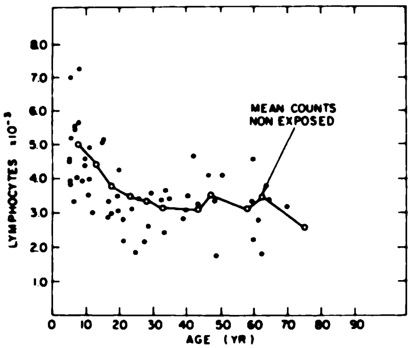

Figure 10. Lymphocyte scattergram of individual counts plotted against age; Rongelap, age >5, 4 years post-exposure. Open circles represent mean counts of comparison population.

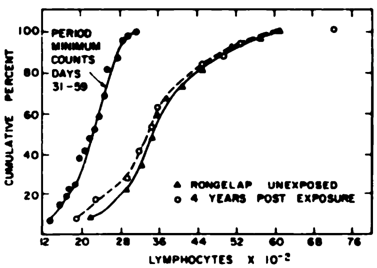

Figure 11. Cumulative distribution curve, Rongelap lymphocytes, age >5.

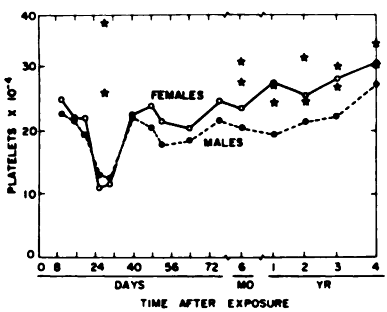

Figure 12. Mean platelet values for exposed Rongelap people from exposure through 4 years post-exposure. Stars represent mean values for control populations.

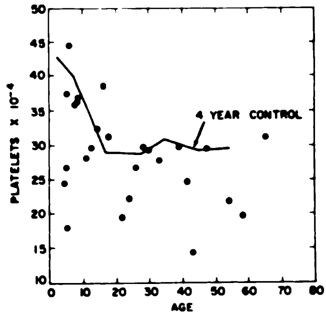

Figure 13. Platelet scattergram, males, of individual counts plotted against age. Solid line represents values for control population.

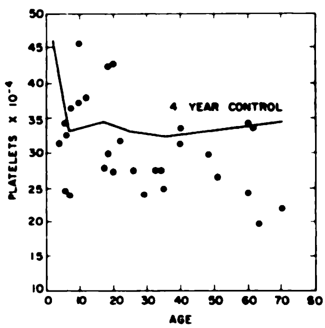

Figure 14. Platelet scattergram, females, of individual counts plotted against age. Solid line represents values for control population.

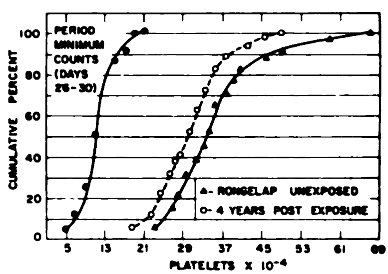

Figure 15. Cumulative distribution curve, Rongelap platelets, all ages.

Hemopoietic reserve. It was of interest to determine whether the hemopoietic reserve of the exposed Marshallese was equal to that of the unexposed group. Means were sought to stimulate or challenge the marrow in regard to white cellular elements, erythroid cells, or platelets, but no feasible methods have been found. However, advantage was taken of a possibility that effects of the natural stress of menstruation and childbearing in the women 15 to 45 years of age might be reflected in differences in levels of their peripheral blood elements. The blood levels in this group of females were compared with those in the same age group of unexposed females, and the differences were then compared with the differences between exposed and unexposed men in the same age groups. Irradiated women and men, 15 to 45 years of age, were found to show the following percentage differences from the unexposed women and men of the same age group: neutrophils, females −5%, males +3%; lymphocytes, females −6%, males −15%; platelets, females −6%, males −7%; hematocrit, females +2%, males −6%. From these data, it did not appear that exposed women showed any lower levels of peripheral blood elements than did the exposed men compared with the unexposed groups, and the stress of these female functions did not appear to cause any noticeable effect.

Hematological Studies of Genetically Determined Traits. Blood grouping studies. The following is taken from a report by Sussman et al.[16] on blood groupings in the Rongelapese.

1) ABO System:

The groupings in this system were as follows.

Group	No.	%	Gene Frequency	
O	75	58.1	0.762	$p_c=0.789$
A_1	24	18.6	0.114	$q_c=0.116$
A_2	0	0		
B	19	15.0	0.093	$r_c=0.095$
A_1B	10	7.4		
A_2B	1	0.8		

The unusual finding of a single A_2B was verified by testing with several absorbed B antisera, as well as with the lectin of *Dolichos biflorans*.[17] The total absence of A_2 genes in Eastern Asia, Australia, and Indonesia has been repeatedly noted.[18,19] Inquiry into the family background of the single A_2B native failed to reveal any significant information leading one to suspect admixture.

2) MN System:

This blood group system was distributed as follows.

	No.	%	Gene Frequency
M	8	6.2	0.14
MN	20	15.5	
N	101	78.3	0.86

The low frequency of the M gene has been noted in the Marshall Islanders by many investigators.[20] The frequencies obtained in this study are among the lowest encountered.

3) Rh-Hr System:

A most unusual distribution was noted in this system. Tests were performed with anti Rh_o (D), rh′ (C), rh″ (E), hr′ (c) and hr″ (e) sera. The results are as follows.

Phenotype	No.	%	Chromosome Frequency
Rh_1Rh_1	126	97.7	$R^1=98.5$
Rh_1rh	3	2.3	

The chromosome frequency of 98.5% for R^1 is the highest reported for any ethnic group. The complete absence of any rh negative persons in these and related series leads one to suspect that the true genotype of the bloods giving a positive reaction with anti hr′ (c) serum is most probably R^1R^o. The occasional finding of an Rh_o person by Simmons[20] supports this interpretation. In the present series of 125 there were no bloods that reacted with rh″ (E) antiserum.

Table 7

Case No.	Age	Sex	WBC ($\times10^{-3}$)	Neut. ($\times10^{-3}$)	Lymph. ($\times10^{-3}$)	Plate. ($\times10^{-3}$)	Hct.
			Exposed				
68	53	M	4.6	2.2	1.7	199	38.7
73	22	M	4.7	2.3	2.1	198	44.0
12	23	F	4.5	1.6	2.8	316	34.0
16*	42	M	4.5	2.2	1.8	247	44.8
58	63	F	5.6	2.2	3.2	219	35.7
30	63	F	5.5	3.7	1.7	197	38.2
11	54	M	5.6	3.2	2.2	218	35.7
			Unexposed				
878	39	M	5.0	2.2	2.2	229	37.5
854	58	F	5.1	2.2	2.7	383	40.3

*Ailingnae.

Table 8

ABO, MN, Rh-Hr, and Duffy-Kell-Diego Frequency Among Marshallese and Polynesians

		ABO system							MN system				
		Group				Gene frequency			Type			Gene frequency	
	No.	O	A	B	AB	p_e	q_e	r_e	M	MN	N	m	n
Marshallese (present study)	129	58.1	18.6	15	8.2	0.789	0.116	0.095	6.2	15.5	78.3	0.14	0.86
Marshallese (Simmons[20])	678	52.2	21.4	121.1	5.3	0.723	0.135	0.134	(10)	(19)	(71)	0.22	0.78
Polynesians (Simmons and Graydon[21])	138	39.1	60.9	0	0	0.626	0.374	0.10	19.6	47.8	32.6	0.435	0.565

	Phenotype Rh-Hr				Gene frequency			Duffy, Kell, Diego		
	Rh_1Rh_1	Rh_1rh	Rh_2	Rh_1Rh_2	R^1	R^2	R^0	Fy^a+	K+	Di^a+
Marshallese (present study)	97.7	2.3	0	0	0.985	0	0.15	89.2	0	0
Marshallese (Simmons[20])	90.6	0.7	0.3	8.0	0.951	0.04	0.006	100	-	-
Polynesians (Simmons and Graydon[21])	19.6	0.7	29.7	50.0	0.449	0.543	0.007	74.6	0	0

4) Duffy System:

In this system 89.2% Duffy (Fy^a) positive bloods were found. A previous report of 100% Duffy (Fy^a) positive reactions[20] (in 30 specimens that had been stored for 16 months) indicates a need for verification and clarification.

5) Other Systems:

Kell tests were 100% negative as previously reported. Diego* tests were 100% negative.

The failure to demonstrate the Diego factor in any of the studies conducted in this area of the world is noteworthy. To date its absence in Polynesians,[21] Maoris,[22] and now in Marshallese becomes a significant finding in view of its occurrence in Mongoloids, Eskimos, and Amerindians,[23-25] to whom Heyerdahl[26] credits the population of the Polynesian Islands.

The gene frequency comparisons with other reports from this area are shown in Table 8.

The above findings indicate a rather homogenous population of the Marshall Islands with extremes of gene frequencies. With some reservations because of the relatively small samplings, the following facts are of interest in the blood groupings of the Marshallese.

1) The extremely high frequency of the O gene (78.9%).
2) The extremely low frequency of the M gene (14%).
3) The highest incidence of the R^1 chromosome yet reported (98.5%).
4) The presence of 10.8% of Duffy (Fy^a) negatives.
5) The absolute absence of Kell and Diego factors.
6) A single example of A_2B in this area.

The investigations of numerous authors, compiled and summarized by Mourant,[18] most nearly relate these blood groupings to those found in Southeast Asia and Indonesia, where relatively frequent B genes are found, a high N frequency exists, and a similar high frequency of the R^1 chromosome is seen.

The absolute absence of the Diego factor, the extremely low incidence of the M gene, and the unusually high R^1 chromosome frequency of the

*We are indebted to Dr. Philip Levine who supplied the anti Di^a serum and Dr. Miguel Layrisse who supplied the Di^a positive cells for control.

Marshallese more nearly resemble the blood groupings of the people of the Western Islands of Indonesia than those of the Amerindians. Too great a generalization of population origin, however, cannot be drawn from such a relatively small study group.

Haptoglobin studies. Results of the haptoglobin studies are taken from a report of Blumberg et al.[27] With the starch gel method of electrophoresis there are three distinct patterns of haptoglobins.[6] In type 1 − 1, there is one haptoglobin travelling near the beta globulin region; in type 2 − 2, there are three haptoglobins travelling between the alpha and beta globulins; and in type 2 − 1, there are four haptoglobins. One of these appears to be the same as in type 1 − 1 and the other three migrate slightly further than the three haptoglobins of type 2 − 2. It has been shown that these haptoglobin patterns are genetically determined, and they also appear to have a physiological function associated with hemoglobin transport.[28,29]

Occasionally an individual is found who has no haptoglobin at all. It is not yet clear if this type is genetically or environmentally determined. In the Marshallese, one such individual was found, and he was excluded in computing the phenotype frequencies. The actual incidence of the haptoglobin types was as follows.

Type	No.	%
1−1	51	40.48
2−1	54	42.86
2−2	20	15.87
0−0	1	0.79
Total	126	100.00

The Marshall Islanders have a very high incidence of the 1 − 1 type of haptoglobin, and incidence of the $H_p{}^1$ gene exceeded only by that of the Yorubas of Nigeria.[30] The Alaskan Eskimos have a low incidence of this type. There appears to be a *prima facie* relationship with latitude; populations from areas near the equator have a high incidence of 1 − 1 and a low incidence of 2 − 2, persons in high latitudes the reverse, and populations from temperate climates intermediate values. There is, of course, no evidence that the relationship is more than coincidental. Another possible correlation is diet; the Artic people live primarily on a protein diet (sea mammals, fish, and caribou), while the Nigerians have a diet with a high carbohydrate content. Further studies are required to confirm or reject this association. The haptoglobin system represents one of the best examples of genetic polymorphism yet described in humans. A study of its incidence in various people may help in elucidating the selective factors that maintain its balance in the population.

Hemoglobin types. In the 45 Marshallese blood samples analyzed, hemoglobin A, was found to be a little more diffuse than in the control samples. There was also an increased smearing of the hemoglobin behind the A_1 zone. However, the hemoglobins were considered to be normal, and the above findings were believed to be due to possible denaturation which caused increased diffusion and smearing of the hemoglobin during electrophoresis.

Serological and Urine Studies. Serum proteins. As noted in the past, the serum protein levels were elevated in both exposed and unexposed people. The mean level of the exposed group was 7.6 g, and of the unexposed group 7.8 g. Electrophoretic studies last year showed the gamma globulin to be elevated.

Tests of thyroid function. The following was reported by Dr. J.E. Rall. The level of serum protein-bound iodine in both groups was significantly above the normal range (see Table 9). The Normal PBI in man in the United States by this technique ranges from 3.5 to 7.5 μg%. There appeared to be no correlation of PBI with either age or sex. The ages of those examined ranged from 6 to 83. The total iodine of these sera averaged 1.0 μg% above the PBI, which is a normal value and an indication that contamination with iodine was not contributing to the elevated PBI values. To determine whether the PBI might consist of other organic but not thyroidal iodine, butanol extractable iodine tests were performed on 6 sera. These values were at the upper limit of normal (normal range 3.2 to 6.4 μg%). To delinate further these findings, thyroxine-binding capacity studies were performed on selected sera by methods previously described.[7] In 12 cases the values averaged 0.26 μg thyroxine/ml serum and ranged from 0.186 to 0.32. The normal value is 0.20 μg/ml, but inadequate data are available to define precisely whether the values in these Marshallese individuals were significantly different from normal. It can, however, be calculated that the level of thyroxine-binding protein is insufficient to cause an elevation of serum thyroxine (presumably to maintain a normal level of free thyroxine) as seen in these subjects. Contamination of the sera with

48338 O—59——27

Table 9

Group	No. people	Av PBI*	Range	No. people	Av BEI	No. people	Av TBC**†	Range
Radiated	36	9.93	6.0—13.6	3	6.6			
Control	24	10.4	7.2—16.4	3	6.2	12	0.26	0.18—.32

*As μg/100 ml serum.
**As μg thyroxine bound (maximal)/ml serum.
†No difference was noted between radiated and control groups, therefore they were not separated for these values.

an organic iodinated material could account for these data, but no source of such contamination is apparent. It must therefore be concluded, pending further study, that the Marshallese showed elevated serum protein-bound iodine levels which may or may not represent thyroid hormone.

Sodium and potassium determination in urine and food samples. Preliminary data on the sodium and potassium determinations in the urine and food samples of the Marshallese indicate that there may be some correlation between the suggestive evidence of hypotension in the people and salt intake. However, further analyses will be made before a final conclusion is reached.

Serum vitamin B_{12} concentrations. The following was reported by Dr. D.W. Watkin. Table 10 shows the mean levels of vitamin B_{12} found in the Marshallese sera along with data on American subjects. The former were all significantly higher than the latter.

The reason for this increased vitamin B_{12} level in the Marshallese serum is not apparent. The possibility of contamination of the samples with bacteria producing vitamin B_{12} must be considered, but no such contamination was grossly evident. Increased B_{12} concentrations in United States medical practice are usually associated with myeloproliferative diseases, liver disease, and frequent parenteral administration of large doses of B_{12}. Increased concentration of B_{12}-binding protein is usually observed in myeloproliferative diseases. The origin of this protein is not known. Perhaps in the Marshallese increased concentrations of B_{12}-binding protein may normally occur.

Table 10

Means, Ranges, Standard Deviations, and Standard Errors of the Means of Serum Vitamin B_{12} Concentrations in USA Normal Subjects, in Exposed Marshallese, in Unexposed Marshallese, and in All Marshallese Examined

Group	No. people	Mean, μμg/ml	Range, μμg/ml	SD, μμg/ml	SE of mean, μμg/ml
USA normal	31	533	260– 850	166	30
Marshall, exposed	44	667	305–1250	260	39
Marshall, unexposed	58	811	194–1705	327	43
Marshall, total	102	749	194–1705	308	30

Survey for Intestinal Parasites. In Table 11 are listed infections found in the two main groups examined. For most parasites the incidence in exposed and unexposed populations was close enough to be considered the same. There were more infections with small race *Entamoeba histolytica* and with hookworm in the unexposed group, and more infections with *Trichomonas hominis* in the exposed group. For the three major pathogens found, the over-all infection rates were *E. histolytica* 18.2%, hookworm 5.5%, and *T. trichiura* 34.3%.

Of the 69 exposed individuals who had stool examinations, 40 had eosinophil counts of 5% or more, and 29 had levels of < 5%. Among the unexposed individuals, there were 60 cases on whom both stool examinations and eosinophil counts were available. Of these, 34 showed eosinophilia, 26 did not. The incidence of eosinophilia of >5% in the over-all population was 50%. The incidence of *Trichuris* was determined in these groups, and it was found that in both exposed and unexposed populations more of the eosinophilia cases had *Trichuris* infections than those with no eosinophilia (Table 12). However, about half the cases with eosinophilia showed no helminth infections at all.

Since infection rates for both exposed and unexposed groups were similar, the following analyses are based on pooled results for both groups.

Table 13 presents the age distribution of infections found. *E. histolytica* was found in 4.6% of 43 children 5 years old or younger. In the 6 to 12 year group, detected infections went up to 23.3%. The

Table 11

Relationship of Radiation Exposure to Infection With Intestinal Parasites

Organism	Exposed (69 cases)	Unexposed (112 cases)	Totals (181)
Entamoeba histolytica	14 (20.3)*	19 (16.9)	33 (18.2)
Entamoeba histolytica (small race)	2 (2.9)	10 (8.9)	12 (6.6)
Entamoeba coli	25 (36.2)	35 (31.3)	60 (33.1)
Endolimax nana	14 (20.3)	35 (31.3)	49 (27.1)
Iodamoeba butschlii	—	3 (2.7)	3 (1.7)
Giardia lamblia	5 (7.2)	9 (8.0)	14 (7.7)
Chilomastix mesnili	4 (5.8)	4 (3.6)	8 (4.4)
Trichomonas hominis	24 (34.8)	30 (26.8)	54 (29.9)
Hookworm	2 (2.9)	8 (7.1)	10 (5.5)
Trichuris trichiura	21 (30.4)	41 (36.7)	62 (34.3)
No parasites	11 (15.9)	30 (26.8)	41 (22.7)

*The number in parentheses is the percent.

highest incidence, 26.8%, was found among adults in the 21 to 50 age group. The other two intestinal amebae, *Entamoeba coli* and *Endolimas nana* occurred much more frequently in the youngest age group, 23.3 and 18.6% respectively, and both showed increases among the older individuals. Among flagellates, the *Giardia lamblia* incidence was highest in the young children and almost nonexistent after the age of 12. *T. hominis* showed a high, relatively unchanged incidence in all age groups.

Of the two helminths found, hookworm showed a steady rise in incidence, from 2.3 to 12.5%, with ages up to 50. No infections were found after 50 years of age. *T. trichiura* occurred in 30.2% of the children 5 years old or less, and in 66.7% of the 6 to 20 year group. In the older age group, 21 to 50, the incidence dropped to 16.1%, rising again after 50 to 31%.

Table 14 shows a breakdown of infections according to sex, with a further division into two age groups, less or more than 13 years of age. Division into the two age groups was made on the basis that both sexes probaly engaged in similar pursuits up to puberty, but that afterwards their daily routines probably differed. Older males had higher incidences than older females, or similar ones, for all parasites except *T. trichiura*, the incidence of which was about half as great in males. Among younger males, incidences tended to be lower than among young females, except that of *E. coli*, which was distinctly higher in the males.

Although differences in incidence of various parasites occurred in exposed and unexposed groups, there is no convincing indication that radiation had anything to do with the variations. In most instances differences can be accounted for by sampling errors in the relatively small numbers of cases studied. In addition, the two groups are not precisely comparable. The unexposed or control group consisted of individuals who had lived on different islands before joining the exposed population of Rongelap. Environmental sanitation had not necessarily been the same for the two groups.

The environment on the coral atolls and the customs of the inhabitants are such that it was not expected that any trematode or cestode infections would be found. However, the complete absence of *Ascaris* in the face of a 34.3% incidence of *Trichuris* was unexpected. Life cycles of both these nematodes in the external environment are such that they are customarily found together. The history of Marshallese association with other peoples, Europeans, Japanese, and Americans, makes it likely that they have been exposed to *Ascaris*. Thus, one is led to the possibility that the external environment on Rongelap Atoll may be unfavorable for *Ascaris* even though very suitable for *Trichuris*. It was not possible to obtain stools from any of the few dogs on the island in order to check for dog ascarids. Several dried pig droppings were examined at one time and no *Ascaris* was found in them. However, in the absence of more epidemiological and experimental information, one can only guess the reasons for the lack of *Ascaris*. Soil moisture, salinity, pH, porosity, etc., may all play some part in this unusual picture.

The fact that half the cases with eosinophilia showed no helminthic infections at all suggests other significant factors causing this blood picture besides parasitic infections. On the other hand, the greater incidence of *Trichuris* among Marshallese with eosinophilia than among those without eosinophilia indicates that infection with that helminth may have been a contributing factor in its incidence.

The incidence of parasites in all age groups indicates that fecal contamination is widespread and that infections are acquired early in life. Although individual Marshallese were generally neat and clean in appearance, their simple sanitary facilities and rural life make it likely that fecal contamination is a continuing affair. The concentration of

Table 12

Relationship of Eosinophilia to Infection With Intestinal Helminths

Organism	Exposed population: Eosinophilia (40 cases)	Exposed population: No Eosinophilia (29 cases)	Unexposed population: Eosinophilia (34 cases)	Unexposed population: No Eosinophilia (26 cases)	Combined population: Eosinophilia (74 cases)	Combined population: No Eosinophilia (55 cases)
T. trichiura	14 (35.0)*	7 (24.1)	17 (50.0)	7 (26.9)	31 (41.9)	14 (25.5)
Hookworm	1 (2.5)	1 (3.4)	5 (14.7)	2 (7.7)	6 (8.1)	3 (5.5)
No helminths	26 (65.0)	21 (72.4)	13 (38.2)	19 (73.1)	39 (52.7)	40 (72.7)

*The number in parentheses is the percent.

Giardia in children conforms to the usual picture for the incidence of this parasite. It would be unwise to ascribe special reasons for differences in infections between the sexes. Not enough individuals were examined, differences show no simple pattern, and the unsettled living conditions of these people during the past few years undoubtedly upset their usual daily routine.

Body Burdens of Radionuclides

Background. Studies of the internally deposited radioactive materials in the Marshallese population exposed to fallout were included in the initial examination in 1954 and have continued to be part of the subsequent re-evaluations. Until the 1957 examination, however, only indirect methods for assaying the body burden, namely urine analyses and extrapolation from animal data, were used. In the 1957 and 1958 examinations, the more direct method of whole-body gamma-ray spectroscopy was added to the procedure.[5]

As documented in the previous reports,[1-5] most of the radioactivity found in the urine specimens obtained during the first 24 days was accounted for by a few relatively short-lived nuclides, I^{131}, Sr^{89}, $Ba\text{-}La^{140}$, and other rare earths. Further analyses of stored 24-day urines performed 2 years later (after decay of the short-lived nuclides) showed that the samples contained averages of 12 d/m/l of Sr^{90} and 174 d/m/l of Cs^{137}. Low levels of $Ce\text{-}Pr^{144}$ were found in the pooled specimens in 1956. In specimens obtained in 1957, the Sr^{90} level had decreased to between 0.34 and 1.41 d/m/l. The Cs^{137} concentration had been down to

Table 13

Relationship of Age of Individuals to Infection With Intestinal Parasites

Organism	Age 1 – 5 (43 cases)	6 – 12 (30 cases)	13 – 20 (15 cases)	21 – 50 (56 cases)	51 and older (29 cases)
E. histolytica	2 (4.6)	7 (23.3)	2 (13.3)	15 (26.8)	5 (17.2)
E. coli	10 (23.3)	10 (33.3)	5 (33.3)	20 (35.7)	14 (48.3)
E. nana	8 (18.6)	4 (13.3)	7 (46.7)	18 (32.1)	9 (31.0)
G. lamblia	8 (18.6)	2 (6.7)	0	1 (1.8)	1 (3.4)
T. hominis	13 (30.2)	11 (36.6)	3 (20.0)	17 (30.4)	8 (27.6)
Hookworm	1 (2.3)	1 (3.3)	1 (6.7)	7 (12.5)	0
T. trichiura	13 (30.2)	19 (63.3)	11 (73.3)	9 (16.1)	9 (31.0)
No parasites	17 (39.5)	3 (10.0)	2 (13.3)	11 (19.6)	5 (17.2)

8 individuals whose age and sex were unknown are not included.

Table 14

Relationship of Sex of Individuals to Infection With Intestinal Parasites

Organism	Male: <13 yr (41 cases)	Male: 13 and over (49 cases)	Female: <13 yr (32 cases)	Female: 13 and over (51 cases)
E. histolytica	5 (12.2)	10 (20.4)	6 (18.7)	12 (23.5)
E. coli	14 (34.1)	22 (44.9)	6 (18.7)	17 (33.3)
E. nana	6 (14.6)	20 (40.8)	6 (18.7)	14 (27.5)
G. lamblia	5 (12.2)	1 (2.0)	5 (15.6)	1 (2.0)
T. hominis	14 (34.1)	11 (22.4)	10 (31.3)	18 (35.3)
Hookworm	0	6 (12.2)	2 (6.3)	2 (3.9)
T. trichiura	18 (43.9)	10 (20.4)	14 (43.8)	19 (37.3)
No parasites	9 (22.0)	8 (16.3)	11 (34.4)	10 (19.6)

8 individuals whose age and sex were unknown are not included.

33 d/m/l in 1956 but rose to between 137 and 370 d/m/l in 1957 (presumably because of slight fallout from a test series).

As part of the 3rd annual survey, several of the Marshallese people were brought back to Argonne National Laboratory for whole-body gamma-ray spectroscopy studies.[5,31] At that time the presence of Zn^{65} as an internally deposited radioisotope was first noted, and the importance of similar studies on the entire Rongelap population was recognized. Since it was not feasible to bring large numbers of Marshallese back to the States for such a study, it was decided that for the 4th annual survey the necessary equipment would be transported to Rongelap. (In view of the frequency of breakdown of the complex electronic equipment even under laboratory conditions, and the severe additional stresses associated with transportation and tropical conditions, complete spare units of the major electronic items were taken, as well as complete sets of spare tubes and other small components.)

Equipment and Procedures. The 1957 measurements at Argonne indicated that, although a good shield would be needed to lower the background, there would be enough radioactivity in the Rongelap subjects to make the shielding requirements less stringent than the criteria used at Argonne for very low body burdens. Accordingly, a steel room was used similar in design to the one at Argonne,* but with the walls and top only 4 in. thick and with the bottom only 2 in. thick. The steel deck of the LST and the water underneath were expected to compensate for the relatively thin bottom shield. With outside dimensions of 5 ft 8 in. by 5 ft 8 in. by 6 ft 6¼ in., the steel room weighed 21 tons.

The crystal found to be most useful as a detector was a sodium iodide (thallium activated) crystal in the form of a right cylinder 5 in. in diameter and 5 in. deep.

Within the steel room the subjects sat in a semireclining chair in a position similar to that used at Argonne.[32-34] The crystal, photomultiplier tube, and preamplifier were suspended above the subject's abdomen. The signal was conducted from the preamplifier to a linear amplifier outside the room and subsequently analyzed with a 100-channel pulse height analyzer. Commercial models* of the analyzer designed by Chase[35] were used. A fan and a phonograph contributed to the subject's comfort within the steel room.**

Before entering the steel room, the subjects took a shower bath and donned paper overalls and slippers. A special facility had been constructed aboard the ship for the shower and dressing station. The subjects were usually counted for 10 minutes.

In order that direct comparisons of body burdens with urinary excretion rates could be made, individual, rather than pooled, 24-hr urine specimens were obtained. The radiochemical analyses of the urines were conducted at the Walter Reed Army Institute of Research.***

One of the subjects died, and in this case the additional comparison of bone radionuclide concentration with whole-body and urine data was made.

The gamma-ray spectral data and most of the electronic equipment from the March 1958 trip were lost at sea, but prominent Cs^{137} and Zn^{65} peaks had been observed in the field, and it was felt that the expedition had proved the feasibility of conducting such measurements under field conditions. As soon as possible, therefore, the lost equipment was replaced and a second survey was conducted in May. By then, however, the 1958 series of weapons tests had begun at Eniwetok. This added to the difficulties because the steel room was taken to Rongelap by ship from Eniwetok, and it was not discovered until arrival at Rongelap that the ship being used (an LCU) was sufficiently contaminated with radioactivity to raise the background enough to interfere with the measurements. In fact, the deck underneath the steel room had been painted with a nonskid paint which evidently included radioactive sand from Eniwetok. The use of a paint remover and generous washing down of the ship reduced the background from 50,000 to 20,000 cpm, which, though still very high, did permit the measurements to be made. In March the background had been 1200 cpm.

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*The authors wish to express their gratitude to Dr. C.E. Miller, Dr. L.D. Marinelli, and Mr. J.E. Rose of Argonne National Laboratory for generous assistance in planning the steel room, including their supplying drawings of the Argonne iron room.

*Technical Measurements Corp., New Haven, Conn.

**Additional information on gamma-ray spectroscopy and sources of data may be found in references 79 to 90.

***We are grateful to Col. James Hartgering, (MC) USA, Maj. Kent T. Woodward, (MC) USA, and Lt. Ariel Schrodt of the Walter Reed Army Medical Center; Dr. John Harley and Mr. Edward Hardy of the New York Operations Office of the AEC; and Dr. Stanton H. Cohn of Brookhaven National Laboratory for assistance in the radiochemical analyses.

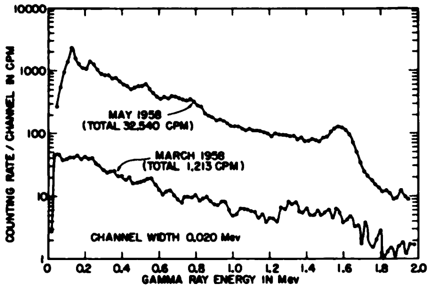

Figure 16. Background counting rates at Rongelap Atoll.

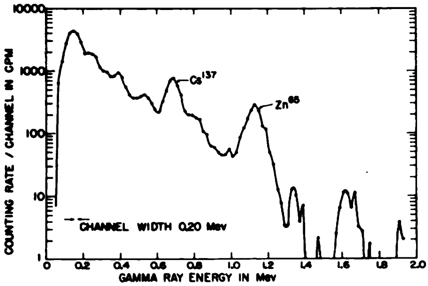

Figure 17. Rongelap subject #50, May 1958, total 43,260 cpm above background.

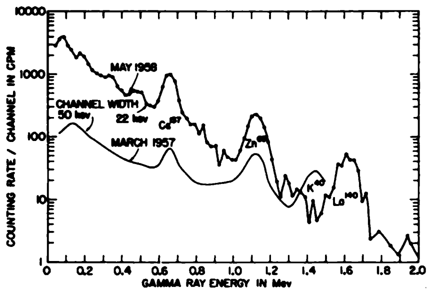

Figure 18. Rongelap subject #79, total 66,974 cpm above background (analysis No. 4).

Findings. Figure 16 compares the background gamma-ray spectrum of March 1958 with that of May 1958. (A few background data, plant and marine specimens, and data on one of the American subjects had been carried separately and hence were not lost at sea.) In addition to its being high, the May background shows a peak at 1.6 Mev, which was attributed to Ba-La^{140}. Except for this one peak, the background spectrum is essentially continuous. This, plus the fact that external procedures were effective in reducing the background, whereas cleaning the inside of the steel room and removal of unnecessary articles from within the room were ineffective, indicated that the contaminating radioactivity was outside the room.

Figure 17 shows the net gamma-ray spectrum of a representative Marshallese subject after appropriate correction for analyzer dead time and subtraction of the background. The Cs^{137} and Zn^{65} peaks are seen to be prominent, and in this case there is also a net peak at 1.6 Mev which has been attributed to Ba-La^{140} and which obscures the K^{40} peak. The latter was not a constant finding, but even in the spectra without it, the K^{40} peak was usually obscured by the high background. It had been hoped that the spectra could be examined for other peaks, but, since the method of analysis requires the high energy peaks and their associated Compton scattering spectra to be subtracted out first, the difficulties introduced by the high background, the 1.6 Mev peak, and the masking of the K^{40} peak render the entire procedure very uncertain. Similar difficulties prevented examination of the spectrum for possible contributions from Sr^{90} bremsstrahlung. If future surveys show the presence of additional nuclides, the 1958 data may be re-examined. For the present, however, only the Cs^{137} and Zn^{65} values, based on peak heights, are reported here.

Figure 18 shows the spectrum for another subject in 1958 compared with his spectrum in 1957. Because of the narrower channel width used in the 1958 study, the activities are even higher relative to the 1957 levels than the graph indicates.

The body content of Cs^{137} and Zn^{65} and the urinary concentrations of Cs^{137}, Zn^{65}, K^{40}, and Sr^{90} are presented in Table 15. Since the urine specimens were obtained in March, they may not correspond strictly to the body data obtained in May. The subjects are divided into groups on the basis of their island of residence. The data are presented in this way rather than on the basis of exposure

Table 15

Internal Deposition and Urinary Concentrations of Radioisotopes in Marshallese People

Case Number*	Age (yr)	Sex	Weight (lb)	Body Cs^{137} (mμC)	Body Zn^{65} (mμC)	Urine Cs^{137} ($\mu\mu$C/l)	Urine Zn^{65} ($\mu\mu$C/l)	Urine K^{40} ($\mu\mu$C/l)	Urine Sr^{90} ($\mu\mu$C/l)
RONGELAP RESIDENTS									
1	58	F	148	442	485				
6	5	M	38	317	544				
7	41	M	129	—	—	2161	161	83	1.56
8	5	F	38	384	138				
9	27	M	135	—	—	1222	99	57	3.78
11	54	M	118	425	147				
12	22	F	120	397	235	2897	261	109	1.53
14	29	F	135	688	532				
15	10	F	58	580	152				
16	43	M	118	552	526				
17	7	F	48	466	135				
18	25	F	108	600	397				
19	9	M	48	370	118				
20	11	M	63	425	108				
23	8	M	52	601	226				
28	3	F	28	312	117				
30	63	F	102	507	361				
31	36	M	138	—	—	3362	236	190	1.20
32	8	M	43	739	320				
34	49	F	112	611	329				
35	17	M	123	905	412				
36	11	M	75	758	262				
37	24	M	134	569	379				
40	33	M	128	495	452	2254	147	72	6.10
41	48	M	126	365	446	2225	106	—	5.29
45	36	F	108	300	223				
47	12	M	77	697	573				
49	20	F	142	671	594				
50	38	M	164	723	829				
66	34	F	111	—	—	2391	22	121	3.09
73	22	M	160	1200	300	5534	145	—	5.62
74	20	F	138	498	300				
79	43	M	137	950	644	3684	120	173	1.97
80	50	M	132	326	429				
82	54	M	131	735	176				
820	9	M	56	471	129				
822	12	M	69	312	220				
823	14	M	95	495	255				
825	16	F	101	—	—	9839	334	234	10.13
830	19	M	141	543	417	5119	549	162	6.69
831	18	M	113	865	420	7276	303	120	2.71
833	25	M	120	649	326				
834	24	M	121	1268	455				
836	25	M	118	923	532	6964	87	319	2.52
840	28	M	142	951	476	3363	1251	113	4.02
842	34	M	130	913	411				
843	29	F	110	—	—	2070	74	57	1.66
851	50	F	158	302	115				
852	54	F	92	567	488				
856	59	M	120	702	241				
875	41	M	136	673	373				
878	58	M	188	617	317				
881	26	M	165	913	743				
882	25	M	123	432	444				
885	18	M	135	827	667				
910	55	M	143	921	723				
915	61	M	—	516	220				
917	40	M	175	1256	811				
918	60	M	209	1165	588				
927	63	M	155	605	335				
933	54	M	169	856	455				
935	60	M	—	639	576				
939	10	M	86	634	397				
940	8	M	54	399	120				

*Numbers >100 are in group exposed to fallout in 1954; numbers <100 are in unexposed group.

Table 15

Internal Deposition and Urinary Concentrations of Radioisotopes in Marshallese People

Case Number*	Age (yr)	Sex	Weight (lb)	Body Cs^{137} (mμC)	Body Zn^{65} (mμC)	Urine Cs^{137} ($\mu\mu$C/l)	Urine Zn^{65} ($\mu\mu$C/l)	Urine K^{40} ($\mu\mu$C/l)	Urine Sr^{90} ($\mu\mu$C/l)
944	33	M	150	955	491				
945	38	F	120	611	432				
947	50	M	—	639	173				
957	50	F	—	290	241				
958	26	M	125	885	335				
963	40	M	145	1770	417				
964	32	M	—	601	185				
966	26	M	—	944	229				
967	14	M	103	1154	438				
971	14	M	93	1053	344				
1001	6	M	—	357	44				
1006	5	M	40	242	532				
1008	47	M	175	798	543				
	Average			666	374	4024	260	139	3.86
				Eniaetok Residents					
4	42	M	150	793	185				
21	7	F	44	453	162				
22	21	F	86	490	273	5864	341	209	5.99
24	17	F	109	469	191				
26	16	M	148	807	461	4291	220	134	2.09
33	5	F	39	553	188				
39	19	F	116	—	—	13011	155	—	NDA
76	15	M	97	805	215	11603	235	70	2.84
818	7	M	47	712	209	7605	99	26	6.37
819	9	M	66	762	294				
838	25	M	132	397	317	1850	322	94	3.51
855	53	F	145	680	214	3147	119	99	2.45
860	68	M	123	741	285				
865	25	F	98	562	493	4625	317	143	4.09
872	14	M	103	921	379	7666	194	164	1.26
873	39	M	140	846	335				
874	11	M	105	681	417	6086	130	78	3.19
876	20	F	117	—	—	2883	161	27	3.29
877	20	M	130	883	502	3281	231	127	1.95
880	37	M	158	1106	658				
887	12	M	130	673	244	11627	395	183	4.66
1010	38	F	—	933	385				
	Average			713	320	6426	225	113	3.47
	Grand Average			677	361	5139	243	134	3.70
				Former Ebeye Residents					
828	18	M	103	523	211				
849	39	M	204	861	544	3845	939	280	5.00
883	46	M	142	—	—	3356	268	167	2.70
973	49	M	—	238	76				
989	10	M	20	317	26				
	Average			485	214	3601	604	224	3.85
				Average Levels Unexposed and Exposed 1958					
Unexposed				747	384	5282	305	135	3.93
Exposed				578	325	4654	173	104	3.42
				Average Levels per kg Body Weight for Island Groups					
Rongelap				2.7	1.5	14.4	0.9	0.5	0.14
Eniaetok				3.0	1.3	26.1	0.9	0.5	0.15
Ebeye				2.4	1.1	9.4	1.6	0.6	0.10

*Numbers >100 are in group exposed to fallout in 1954; numbers <100 are in unexposed group.

or nonexposure to fallout in 1954, since the body burdens of the two groups are indistinguishable (see mean values for the two groups at the end of Table 15), and the present environmental contamination appears to be the important factor in determining their present body burdens. The island of Eniaetok (about 10 miles north of Rongelap Island) where some 50 Marshallese were living is slightly more contaminated than Rongelap Island itself where the majority of the people live. The Eniaetok group, however, had moved to Rongelap about a month prior to arrival of the team for the whole-body gamma analysis, and the lack of appreciably higher body burdens of this group is probably influenced by this fact. The Ebeye group had also moved to Rongelap Island from an uncontaminated island about three months prior to the May determinations, which probably accounts for the fact that their body burdens approach the Rongelap levels.

Samples for Sr^{90} analysis were taken from a vertebra and from the ileum of the 35-yr-old Rongelap man (No. 31) who died in April 1958. The results indicated a concentration in these bones of 3.7 $\mu\mu C$ Sr^{90}/g calcium.*

Analysis for Sr^{90} was carried out on 7 premolar and molar teeth (pooled) removed in May 1958 from Rongelap residents (exposed and unexposed). A value of 0.95 $\mu\mu C$ Sr^{90}/g calcium was found. This is considerably lower than the bone values found in case No. 31, as would be expected, because of the relatively slower turnover rate of strontium in teeth compared with bones.

A summary of the data on urinary excretion of radionuclides by the Rongelap people for the past 4 years is presented in Figure 19, and on estimated body burden in Figure 20.

Discussion of Body Burdens. In a discussion of the body burdens of the Marshallese it is well to recall the following historical points: (1) For the first 2 days after the accident in 1954, the people lived in a highly contaminated environment with little or no effort to avoid ingestion of fallout materials. This was reflected in their initially high urinary level of radionuclides. (2) For the following 3 years (until July 1957) they lived on a relatively uncontaminated island at Majuro Atoll, during which time the radiochemical urinalysis showed a rapid decrease of radionuclide concentrations. (3) In July 1957 they returned to Rongelap, which had been carefully surveyed for radioactivity and was considered to be safe for their habitation. However, low levels of activity do remain on the island, and these low levels are reflected in the increased body burdens and urinary concentrations observed.

In Table 15 the urine concentrations are expressed in $\mu\mu C/l$. Since 1 $\mu\mu C/l$ corresponds to 2.22 d/m/l, the 1958 concentrations of Cs^{137} are increased by factors of up to 100 over the 1957 concentrations, and that of Sr^{90} is increased by a factor of about 20 (see Figure 19). As previously noted (Figure 18), gamma spectroscopy shows a concomitant increase in the Cs^{137} and Zn^{65} body burden levels in 1958 over those seen in 1957 (see also Figure 20).

Considerable individual variation in body burdens is apparent, but the various groups in Table 15 are not greatly different from one another. There is some correlation of body Cs^{137} and Zn^{65} with body weight, but the variation is great. The correlation of body burden with urinary concentrations of Cs^{137} and Zn^{65} is not very good. The high urinary Cs^{137} level in Eniaetok residents is not matched by much higher body burdens of Cs^{137}.

Using the average values and an estimated 24-hr urine volume of 1450 ml, division of the urinary excretion rates by the body burdens indicates that 1.05% of the body burden of Cs^{137} is excreted daily, but only 0.106% of the body burden of Zn^{65} is excreted daily. It is not known whether the people are in metabolic equilibrium with the radionuclides in this environment. However, taken as steady-state values and assuming only urinary excretion, these figures would indicate biological half-times of 140 days for Cs^{137} and 110 days for Zn^{65}, values considerably at variance with the 17 days for Cs^{137} and the 23 days for Zn^{65} quoted in the recommendations of the National Subcommittee on Permissible Internal Dose.[36]* A value of 145 days for Cs^{137} has been calculated by Anderson.[37] The shorter value for the Cs^{137} biological half-time can probably be explained as being due to prompt excretion of recently ingested cesium. The zinc data, on the contrary, suggest an unusual retention, which could, for example, result from a deficiency of this element, but there are no data at hand to support such a theory.

The body burdens of Sr^{90} appear to be well below the maximum permissible levels (100 Sr^{90}

*This analysis was obtained through the Health and Safety Laboratory, AEC, NYO.

*However, the new Handbook values soon to be published indicate a biological half-time for Cs^{137} of 70 days.[91]

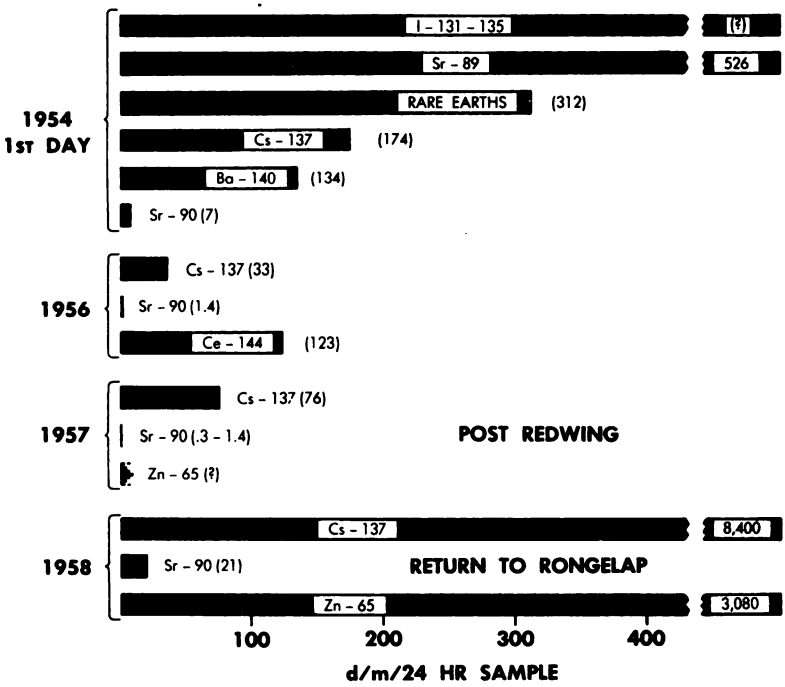

Figure 19. Urinary excretion of isotopes by Rongelap people.

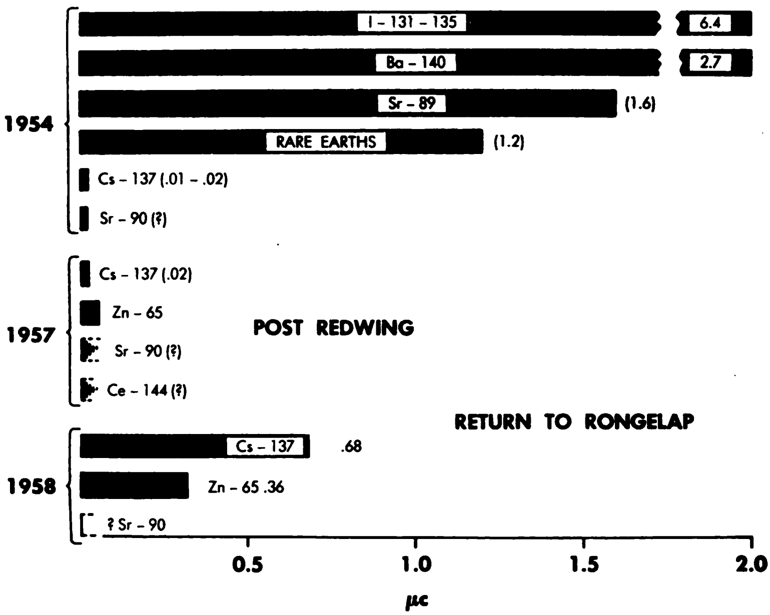

Figure 20. Estimated body burden of isotopes of Rongelap people.

units for populations at large) based on analysis of a small sample of bones from the Rongelap man who died in April 1958, if this sample is representative. Since children may have levels higher than those of adults by a factor of 10, their values may be as high as about ⅓ of the stated maximum permissible concentration (30 to 40 $\mu\mu C$ Sr^{90}). However, this estimate is based on bones of American children and, since consumption of milk by the Marshallese children is practically nil compared with that by American children, this extrapolation may not be valid. Based on urine analyses for Sr^{90} excretion, the average 1958 level was 3.42 $\mu\mu C$ Sr^{90}/l urine, or about half the level found during the first month post-exposure (6.2 $\mu\mu C$ Sr^{90}/l urine). It is not known whether the body burdens of Sr^{90} in the Rongelap people have yet attained equilibrium with their environment, and this point will be carefully followed in future studies.

Although the rapid rise of the Ebeye people's values toward those of the other Rongelap residents suggests that equilibrium values have been approached, the daily excretion rates indicate that equilibrium with the environmental values cannot be assumed. In any event, the increase in activity between the 1957 and 1958 surveys and the similarity of the results for the exposed and unexposed groups indicate that most of the radioactivity seen is the result, not of the initial contamination, but of more recent ingestion of food containing radionuclides. It is known from other studies[38-44] that the soil and food plants on Rongelap contain low levels of fallout products. Eating of land crabs has been proscribed because of their relatively high Sr^{90} content. Among other foods the pandanus fruit shows the highest Sr^{90} content, but this fruit represents a relatively small part of the diet. Other plant foods such as coconuts and breadfruit have relatively low levels of Sr^{90} activity. These plants also contain low levels of Cs^{137}.

Calculations of the radiation dose rates on the basis of existing data are subject to much uncertainty, but have been attempted because of the great interest in this facet of the problem. Using the assumptions accepted in the United Nations report,[45] the 3.8 $\mu\mu C$ of Sr^{90}/g calcium found in the one subject autopsied corresponds to a dose rate of 9.5 mr/year to the bone, and a dose rate of only 3.8 mr/year to the bone marrow. Similar calculations for Cs^{137} and Zn^{65} give a total of about 120 mr/year from the known internally deposited radioisotopes. This is to be compared with the dose rate from natural sources,[46] of which 44 mr/year are attributed to K^{40}, radium, and mesothorium distributed internally and 134 mr/year to cosmic rays and local external gamma sources. From local external gamma sources the Rongelap people as measured in March 1958 were receiving about 250 mr/year and in August 1958, 500 mr/year. (The latter increase was due to slight additional short-lived fallout from a then current test series and the integrated dose for the year might be expected to be $<$500 mr.)

Discussion

ACUTE AND SUBACUTE EFFECTS

The results of the medical survey on the Rongelap people 4 years after exposure to fallout show that the people have largely recovered from the acute and subacute effects of their exposure and are making satisfactory readjustment to their repatriation on Rongelap Atoll.

The acute effects of radiation that were observed early in these people were indicative of significant exposure. Findings unquestionably related to their exposure were early gastrointestinal symptoms and significant depression of the peripheral blood elements commensurate with the calculated dose of 175 r penetrating gamma radiation, beta burns of the skin and epilation from skin irradiation, and the acquisition of a low level body burden of radionuclides. In addition certain other findings were possibly related to their exposure such as (1) loss in weight of several pounds in most of the people during the first several months after exposure and (2) suggestive evidence of a slight lag in growth and development of exposed children during the first 3 years based on studies of height and weight and bone development. (A reevaluation of these studies is necessary in view of uncertainty in ages of some of the children.)

Other acute and subacute effects of whole-body irradiation which have been reported to occur have not been observed in the Marshallese. (1) Fertility, based on comparison of frequency of pregnancies, did not appear to be affected; (2) no deleterious effects were noted on the course of pregnancies; and (3) the four *in utero* irradiated babies appeared normal. It should be reiterated that completely negative statements cannot be made based on these findings because of the pau-

city of vital statistics in the Marshallese and the small numbers of people involved.

No diseases, infectious or noninfectious, have developed which could be related directly to radiation effects. The incidence of diseases in the exposed people noted during the 4-year survey, as in previous surveys, remained about the same as found in the unexposed comparison population. A limited survey of immune responses of the exposed group at 3 years post-exposure[5] showed that the antibody response to tetanus antigenic stimulus was not significantly different from the response in the unexposed group.

Three deaths have occurred in the exposed people. The first was in a 46-yr-old man who died of hypertensive heart disease 1 year post-exposure. He had had the disease at the time of irradiation. The second occurred in a 78-yr-old man at 2 years post-exposure. He was a diabetic of long standing and died apparently of coronary heart disease. A third occurred in April 1958, after the present survey, in a 35-yr-old man from the group that received 69 r, due to pneumonia complicating a severe case of chickenpox. In none of these cases was there any direct evidence that death was due to radiation exposure.

Lag in recovery of some of the peripheral blood elements of the exposed people over the 4-year period since exposure is in sharp contrast to the much more rapid recovery seen in animal studies, but generally conforms to the recovery pattern seen in the Japanese exposed at Hiroshima and Nagasaki. In the Marshallese the myelocytic series showed earliest recovery (by 1 year post-exposure), with lymphocytes and platelets exhibiting much slower recovery. The present hematological examinations reveal that the mean leukocyte level has virtually recovered to the control level, but more individuals had lower counts than in the unexposed group. Thrombocyte production still does not appear to have recovered completely as evidenced by the lower mean levels in the exposed people both individually and as a group. As has been pointed out, however, the slightly lower peripheral blood level of these elements has not impaired in any observable way their resistance to disease.

There has been considerable speculation as to whether there is a lowered reserve hemopoietic capacity in the marrow of the exposed people. The effect of the natural stresses of childbearing and menstruation in women 15 to 45 years of age was examined by comparing differences between the mean peripheral blood element levels of this group and the corresponding group of unexposed women with differences between levels in exposed and unexposed men of the same age group. No significant differences were seen.

It might be questioned whether or not the present low body burden of radionuclides might contribute to delayed recovery of hemopoietic function. Admittedly little is known of possible effects of such low level exposure on the marrow, particularly if, as in the case of the Marshallese, a significant dose of penetrating radiation has been previously received. However, it is not believed that the small amount of additional radiation imposed on the marrow from this source would be sufficient to retard hemopoietic recovery.

Hematological examination at 3 years post-exposure revealed a drop in the mean leukocyte counts compared with 2-year levels in both the exposed and unexposed people. The possibility was considered that a population trend downward in leukocyte counts was occurring such as has been seen in Japan.[47] However, this does not seem to be the case, since leukocyte levels this year are not further depressed compared with previous levels.

The acute effects of the beta irradiation of the skin subsided rapidly, and only 12 cases still show residual scarring and pigment abberation. It is possible that the acute stage of the beta burns may have caused some of the fluctuation observed in the white blood cell count. In those showing epilation, complete regrowth of hair occurred by 6 months post-exposure.

No acute effects of the internal absorption of radionuclides were observed.

LATE EFFECTS

Late effects of radiation exposure have not been seen, but certain of the more fundamental of these effects that have been observed in animals and to a lesser extent in man will be mentioned in relation to the Marshallese.

Shortening of life span[48-52] has not been evident. The 3 deaths that have occurred in the exposed population do not appear to indicate a higher mortality rate than seen in the comparison populations. From these observations it would appear that some of the higher estimates of life shortening per roentgen may be too high.

Premature aging[48,53] is difficult to assess. From observations over the past 4 years the impression is

that exposed people neither have aged faster nor appear older than similarly aged unexposed Marshallese. No doubt the subtle changes which occur with aging would be difficult to detect over this period of time. During the 4-year survey, data were collected in an attempt to obtain semiquantitative estimates of biological age by scoring the degree of certain criteria such as greying of the hair, skin looseness, skin retractility, arcus senilis, retinal arteriosclerosis, accommodation, blood pressure, etc. These data have not yet been completely analyzed.

Degenerative diseases[54-56] have not been found to be increased in the exposed people. No ***malignancies*** have been detected. In the irradiated Japanese an increased incidence of leukemia has been noted.[57-59] There have been no cases of ***leukemia*** or ***leukemia tendency*** noted in the Marshallese. (No cases have shown decrease in alkaline phosphatase of neutrophils, nor have increased levels of basophils been noted.) Since the incidence of malignancy or leukemia would be expected to be relatively low with the dose of irradiation received, and since such a small population is involved, the probabilities are good that such effects will not be observed in the Marshallese.

Ophthalmological changes related to late effects of radiation[13-15] have not been seen. Slit-lamp observations over the past 4 years have revealed no polychromatic plaques or cataracts. No differences were found in visual acuity in the exposed and unexposed children.

Genetic effects.[60,61] No specific studies for genetic effects have been conducted. Of the 18 babies born to irradiated parents and living at the time of examination, none showed any abnormalities. In view of the generally negative findings in the studies of the first-generation offspring of the irradiated Japanese,[62] it is unlikely that genetic studies in this group will be fruitful.

Beta irradiation. No late effects of beta irradiation of the skin such as chronic dermatitis or premalignant changes have been found in the Marshallese.

FINDINGS COMMON TO BOTH EXPOSED AND UNEXPOSED GROUPS

Certain findings common to both exposed and unexposed Rongelap people may have possible significance in relation to their state of health and future prognosis. Clinical laboratory examinations have revealed a complexity of findings difficult to evaluate. Principal among these is the anemic tendency in the population at large. Hematocrit values of 38% or less were found in 54% of the men, and of 36% or less in 78% of the women. Also possibly related to this finding was the increase in reticulocyte counts (>3%) in about 20% of the people noted during the 3-year examination. The following have been considered as possible etiological factors:

1) Nutritional deficiency, such as low dietary proteins or iron deficiency. Although the diet is extremely limited and fish supplemented by small amounts of other meats are about the only source of proteins, there is no good evidence that such a deficiency exists. In fact the blood proteins are high (average 7.8 g%). It is not known whether the diet is deficient in iron. Blood smear examinations did not reveal any obvious microcytosis of red cells. The nature of the anemic tendency will be further investigated in the next survey by carrying out serum iron determinations and running Price-Jones curves of the red blood cells. Poor absorption or deficiency of vitamin B_{12} is apparently not a factor since the levels of B_{12} in the serum were surprisingly high. (Experience with *Diphyllobothrium latum* infestation suggests that parasitism of the gastrointestinal tract should be associated with low vitamin B_{12} serum concentrations.) The relatively high values of serum vitamin B_{12} are puzzling, and no immediate explanation is apparent.

2) Intestinal parasitism is very prevalent, 72% of the people showing stools positive for ova and parasites. However, examination of these stools for occult blood showed positive tests in only 10 people. Chronic blood loss from this source does not seem likely; also, anemia is not usually associated with the parasites found in these people.

3) Chronic infections, particularly skin diseases and dental caries, may play an etiological role in the production of the anemic tendency. The high plasma protein levels with high gamma globulin component may be a reflection of such infectious processes.

The presence of eosinophilia in the population is another puzzling problem. (About half the people show eosinophils >5% in their differential counts with quite a few values as high as 20 and 25%.) Offhand, it might seem that the high incidence of intestinal parasites might account for the high eosinophil counts. However, as pointed out, most of the types of parasites found are not

usually associated with a consistent eosinophilia, and indeed a large group of individuals with high eosinophil counts had stools negative for parasites. However, the greater incidence of eosinophilia among Marshallese with stools positive for *T. trichiura* indicates that infection with this helminth may be a contributing factor, but this does not entirely explain the generally high incidence noted. Possibly chronic infections, particularly fungus infections of the skin, may be partly responsible. Another possibility is trichinosis infestation, which has to be considered seriously in view of the large number of rats on the island and the presence of swine (used to a small extent for meat) roaming freely. On the next survey serological tests for trichinosis antigen will be carried out.

An unexpected finding was that the level of serum protein-bound iodine in these people was significantly above the normal range. Butanol-extractable iodines on 6 cases also showed values at the upper limit of normal, but thyroxine-binding capacity determinations on 12 cases gave data inadequate to define precisely whether the slight elevations were significantly different from normal. However, it could be calculated that the level of thyroxine-binding protein was insufficient to cause the elevation of serum thyroxine (presumably to maintain a normal level of free thyroxine) noted in these people.

The study of genetically determined traits has proved most interesting in helping to establish the anthropological background of the Marshallese people and the homogeneity of the population under study. Interesting findings in the studies of blood groupings were the high frequency of the O gene (78.9%), the extremely low frequency of the M gene (14%), the highest incidence yet reported of the R′ chromosome (98.5%), the presence of 10.8% of Duffy (Fy^a) negatives, the absence of Kell and Diego factors, and a single sample of the A_2B group. These groupings most closely resemble those of the people of Southeast Asia and Indonesia. Haptoglobin studies showed a very high incidence of the 1 − 1 type and the Hp′ gene exceeded only by that of the Yorubas of Nigeria. No unusual hemoglobin types were noted. These findings suggest a rather homogenous population.

RADIATION ECOLOGICAL STUDIES

It seems appropriate to discuss the Marshall Island data as part of the world-wide fallout problem. There has been much concern expressed both in scientific journals and in popular articles about the hazard from fallout, particularly Sr^{90}. The general situation as of mid-1957 has been reviewed by Robertson and Cohn,[63] with the conclusion that existing levels of radiation from fallout add little to the environmental radiation hazard. Eisenbud and Harley[64] present data indicating that in the United States Sr^{90} continues (in 1958) to be deposited at a rate of 11 to 54 mC/mi². The average for the rest of the Northern Hemisphere is 16 mC/mi², which is about twice the value for the Southern Hemisphere. Kulp and Slakter[65] conclude that the diet of an average U.S. citizen in 1957 contained about 6.5 $\mu\mu$C Sr^{90}/g calcium, which corresponds to an equilibrium base level of 1.6 $\mu\mu$C/g if the discrimination factor between diet and bone is 4. Finkel,[66] in an appraisal of the potential Sr^{90} danger based on data from animal experiments, concludes that the minimum effective dose in man may be a burden of from 5 to 10 μC Sr^{90}, in close agreement with an estimate of 6 to 15 μC based on the radium method of extrapolation. Hindmarsh et al.[67] have re-evaluated the relative hazards of Sr^{90} and Ra^{226}. Their conclusion is that the currently accepted maximal permissible dose figures for Sr^{90} are substantially correct. Brues[68] reviews the arguments upon which is based the fear that very low doses of Sr^{90} might produce a "very low (but in absolute numbers appreciable) incidence of leukemia" and concludes that the present data fail to indicate a linear relationship for dose and effect at low doses. He further emphasizes the fact that there are other theories of the etiology of cancer, and that their existence weakens the arguments of those who would assign unrealistically high probabilities to the role of single mutations as being the cause of cancer.

Gilliam and Walter[69] have studied the trends in the mortality from leukemia. In most age groups the death rate has been increasing exponentially since 1921, with doubling times of about 15 to 20 years for most age groups. The younger age groups, however, have recently shown a tendency to level off, or, in the authors' words, since 1940 there has been "a distinct tendency toward a decline in the rate of increase." This tendency is more definite with decreasing age, and in the age group 0 to 1 year there has been an actual decline in the death rate from leukemia. If leukemia follows from exposure to an environmental factor,

the mortality data suggest that exposure of the population to this factor has decreased recently.

Schwartz and Upton[70] have considered the role of ionizing radiation in the general incidence of leukemia and lymphomas. Among other factors considered are age, race, sex, geographical location, climate, genetic factors, constitutional factors, and other extrinsic agents such as chemicals and infectious agents. These authors consider the increase in radiation background from all causes (medical, dental, fallout, etc.) to be "clearly not sufficient to account for the tremendous rise in the recorded incidence of leukemia..." Burnet[71] points out that the present peak of incidence of leukemia at age 3 to 4 is a relatively recent development and suggests the possibility that exposure to some new mutagenic agent at the time of birth is the cause. He cites data which indicate that at most 5 to 10% of leukemia incidence in the United States can be ascribed to radiation from all sources, and points out that the etiology of the other 90% is unknown.

Other constituents of fallout have not received as much publicity as Sr^{90}, but their study has not been neglected.[72-78] Anderson[72] reports an extensive series correlating Cs^{137} and K^{40} levels in people and in milk supplies. He states that the importance of Cs^{137} relative to Sr^{90} is increasing. The levels in both people and milk representing various locales in the United States ranged up to 60 $\mu\mu$C Cs^{137}/g K, with fairly good correlation between the two levels. These results are consistent with those reported by Miller and Marinelli,[78] who have further data suggesting a rather uniform distribution of fallout in the Northern Hemisphere.

The significance of low doses of radiation has not been evaluated fully, the chief reason being the absence of positive data on low-dose effects, particularly in humans. Perhaps more subtle methods will be found by means of which low-dose effects can be documented, but it is to be hoped that the radiation dose can be maintained below the level at which effects appear with any method.

In the meantime, the Rongelap people provide an interesting group of subjects exposed to a level of radiation appreciably above the world average. Present indications are that the body burdens of radionuclides will not reach levels which, from known data, will result in morbid processes. As pointed out before, the development of leukemia associated with their exposure to a sublethal dose of gamma radiation in March 1954, based on experiences with the exposed Japanese,[57-59] is held to be improbable, particularly in view of the small number of people involved. The superimposition of the low level body burdens from environmental contamination would not seem likely to be sufficient to increase this possibility substantially.

The habitation of these people on Rongelap Island affords the opportunity for a most valuable ecological radiation study on human beings. Since only small amounts of radioisotopes are necessary for tracer studies, the various radionuclides present on the island can be traced from the soil through the food and into the human being, where the tissue and organ distributions, biological half-times, and excretion rates can be studied.

Summary

The medical survey of the Rongelap people in March 1958, 4 years after exposure to accidental fallout radiation, was carried out at Rongelap Island, to which these people had been returned in July 1957 after the radiation level of the island was declared safe for habitation. They were adjusting satisfactorily to life in their newly reconstructed village.

No apparent acute or subacute effects were found at this time related to the gamma dose of 175 r received, with the possible exception of hemopoietic findings indicating a persisting lag in complete recovery of platelet levels of the peripheral blood. In the males these mean levels were 11 to 16% and in the females 9% below the corresponding mean levels of the comparison population. The lymphocytes had recovered to a level about the same as in the comparison population, although many of these counts were lower than in the latter group. The stress of childbearing and menstruation did not appear to be reflected in any lowered hemopoietic reserve in the exposed women, based on comparative studies of the levels of peripheral blood elements. The suggestive incidence, previously reported, of slight lag in growth and development of the irradiated children at 2 and 3 years after exposure, based on height, weight, and bone age studies, needs re-evaluation in the light of the finding that the ages of some of the children were not as firmly established as previously thought. History and physical examinations revealed no clinical evidence of any illnesses or findings during the past year or at the time of the present survey which could be related to whole-body exposure.

Two deaths occurred in the exposed and one in the unexposed group since the last survey. The deaths in the exposed group did not appear to be related to radiation exposure. Diseases, infectious and noninfectious, were as common in the exposed as in the unexposed people. Nutrition appeared good except for slight hemeralopia in several children ascribed to vitamin A deficiency. The birth rate was about the same in the exposed as in the unexposed group, and the babies appeared normal.

No late effects of exposure were noted. Shortening of life span has not been observed. The death rate has been about the same in the exposed as in the unexposed population. Premature aging of the irradiated group has not been grossly visible. No radiation opacities of the lens or differences in visual acuity have been noted. No malignancies have been observed, and the incidence of degenerative diseases was about the same as in the unexposed group examined. Genetic studies have not been carried out, but no difference in the incidence of congenital abnormalities has been noted in the first-generation children of the exposed compared with the unexposed populations.

The only residual effects of beta irradiation of the skin were seen in 12 cases which showed varying degrees of pigment abberation, scarring, and atrophy at the site of deeper burns. In no case was there evidence of chronic radiation dermatitis or premalignant or malignant change in the lesions.

The return of the Rongelapese to their island (which has a persisting low level of radioactive contamination) is reflected in a rise in their body burdens and increased urinary excretion of certain radionuclides. Estimates of these body burdens of radionuclides were determined by gamma spectroscopy and by radiochemical analyses of urine samples. These estimates showed that the body burden of Cs^{137} had increased by a factor of 100 and of Sr^{90} by a factor of 10, with some increase in Zn^{65} also, since the return to Rongelap. However, the levels were well below the accepted maximum permissible levels. Analysis of bone samples on one of the men who died showed 3.7 Sr^{90} units/g calcium. Further detailed studies on the radiation ecological aspects of these surveys, including examinations of the food and human metabolism of these isotopes, is in progress and will be an important part of future investigations.

The survey team devoted considerable attention to other medical studies in the Marshallese not directly related to radiation effects but possibly having some bearing on prognosis. Findings in these studies were common to both the exposed and unexposed populations. An extensive intestinal parasite survey showed that the people were infected with many types of protozoa and helminths, although this finding did not entirely account for the generally higher incidence of eosinophilia. Among other findings that need further explanation are the general anemic tendency, the high plasma protein levels with increased gamma globulin, and the high levels of serum protein-bound iodines and vitamin B_{12}. It is hoped that some of these problems will be solved in future surveys.

Another group of investigations concerned the anthropological background of the Marshallese based on studies of genetically determined traits. Among these were determinations of various blood groups and of hemoglobin and haptoglobin types. These studies are shedding some light on the origin of these people and on the homogeneity of the population being investigated. Their blood groups resemble most closely those of people from Southeast Asia and Indonesia, and the population appears to be relatively homogenous.

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Medical Status of Rongelap People 5 Years After Exposure to Fallout Radiation

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In March 1959 the regular annual medical survey was carried out on the Rongelap people who had received the heaviest exposure to radioactive fallout 5 years previously in the accident which occurred following the experimental detonation of a nuclear weapon.

The examinations were conducted on Rongelap Island to which the people had returned in July 1957. On their return, they were accompanied by an equally large group of unexposed relatives. This latter group has served as a comparison population for the medical studies. The Navy kindly furnished an LST for the survey.

These annual surveys are carried out under the direction of Brookhaven National Laboratory and sponsored by the Atomic Energy Commission with the support of the Trust Territory of the Pacific Islands, the Department of Defense, and other governmental agencies. A team of 20 physicians, scientists, and technicians, specialists in the field of radiation medicine, carried out the survey on Rongelap Island.

On arrival of the team at Rongelap there was some question in the minds of some of the people as to the necessity of having further examinations. Objections to the examinations were mainly directed toward their dislike of the blood sampling. It was also evident that the need for the examinations created some concern in the minds of the people about their health status. Some also were concerned about the radiological safety of their food and water for consumption. The people were reassured that their health was generally good and their food and water safe for consumption, and the importance of continued examinations and treatment in order to help insure their continued good health was stressed. These explanations appeared to alleviate their fears and the people cooperated extremely well with the medical team in carrying out the examinations.

The examinations included medical histories, complete physical examinations, and blood and other laboratory examinations. In addition spectrographs of gamma ray activity were obtained from individuals measured in a steel room and from radiochemical analysis of urine samples in order to determine their body burdens of radionuclides. Analyses of the data are not complete and those data referring to this recent survey must be considered as preliminary in nature. In conjunction with the examinations, considerable medical and dental treatment of the people was carried out to the extent possible under field conditions.

Following the accident, the Rongelapese had shown signs of significant exposure to radiation such as short-lived loss of appetite, nausea, vomiting, depression of their blood forming tissues, multiple burns of the skin from beta exposure and internal absorption of fission products.

Findings on the past survey revealed that the people have recovered from the acute effects of their radiation exposure. No diseases, illnesses, or deaths have occurred which could be directly related to their radiation exposure. The incidence of all diseases noted has been about the same in both the exposed and unexposed groups examined. The general physical condition of the exposed and unexposed people on the island appeared good and their nutritional status was satisfactory. During the past year one death occurred in a 35-year-old man, bringing the total deaths in the exposed group to 3 for the 5-year period. This represents a death rate about equal to that of the Marshall Islands as a whole (about 7 deaths per 1,000 population per year).

Findings, previously reported, which were interpreted as suggestive of a slight lag in growth and development of the children during the first few years after exposure are being reevaluated based on more exact age data obtained on the past survey. The results of this evaluation are not complete enough to make any statements at present.

One case of cancer (ovarian) developed in a 61-year-old female during the past year, the first case of cancer noted in either the exposed or unexposed populations. There is no reason to believe the cancer is related to radiation effect.

Fertility does not appear to have been affected since the birthrate has been higher in the exposed than in the unexposed Marshallese. A somewhat increased prevalence of miscarriages and stillbirths has been noted in the exposed group, but due to the paucity of vital statistics on the Marshallese and the small number of people involved, no statistical analysis is possible.

Recovery of the blood-forming tissues is judged virtually complete based on studies of the peripheral blood counts. A possible exception is seen in the blood platelets which are slightly below the levels in the unexposed group but still within the normal range. There is no evidence of any untoward effect associated with this finding.

The beta burns of the skin healed rapidly during the first few months after exposure. In 12 cases there remain slight scarring of the skin and pigment changes at the former site of deeper burns. However, no evidence of any cancerous change in these scars is noted. In those that lost hair, regrowth of normal hair was complete by 6 months after exposure.

Very little is known about late effects of radiation in human beings. Increased incidence of leukemia in the exposed Japanese people has been noted and, in animal studies, the following late effects of radiation may result: Life shortening, premature aging, increase in degenerative diseases, increased incidence of malignancies, opacities of the lens of the eyes, and genetic changes. The Marshallese have been examined for evidence of such changes, but none have been seen. Radiation-induced leukemia is known to appear relatively soon after exposure and other types of malignancy at later times. Therefore, continued examination are essential in order to detect and, if possible, treat such effects should they develop.

The radioactive fission products that had been absorbed internally by the Rongelap people were never sufficient in amount to result in acute effects. These radioactive materials were excreted rapidly during the first 6 months after exposure. The island of Rongelap remains slightly radioactively contaminated, but careful surveys showed the island to be safe for habitation by the summer of 1957 when the people were returned to Rongelap. Studies of the body burdens of radioactive materials in these people is an important part of the medical surveys. A 21-ton steel room with very sensitive radiation-detecting equipment has been used in the past two annual surveys at Rongelap to determine the body burdens of radionucleides. In addition numerous urine samples have been analyzed for radioactivity. The results of these studies show that there has been an increase in body burdens, principally of cesium 137, zinc 65, and strontium 90 since their return to Rongelap. About the same levels of these isotopes have been noted in those exposed and unexposed.

During the first 8 months after their return to Rongelap their body burden of cesium 137 are estimated to have increased by factors up to 100 (resulting in a mean body burden of 0.68 μc); zinc 65 is estimated to have shown a concomitant increase (mean body burden of 0.36 μc); strontium 90 showed about a twentyfold increase rate of excretion in the urine. Only one sample of bone is available for estimating the body burden of strontium 90. This is from a Rongelap man who died in April 1958 (9 months after his return to Rongelap) which showed 3.6 $\mu\mu c/Sr^{90}/gm$ Ca (strontium units). On the basis of North American data, it is expected that the values for children would be higher.

Based on preliminary analysis of data from the most recent survey (8 to 20 months after their return to Rongelap), it appears that the people have begun to attain equilibrium with their lightly contaminated environment. The cesium 137 levels appear to be slightly lower than the year before, while the zinc 65 has increased slightly. The strontium 90 analyses, unfortunatley, are not available yet. The body burdens estimated above are far below the maximum permissible levels; cesium 137 is about 2 percent of the MPL, and zinc 65 is 1 percent of the MPL.

In summary, a medical survey of the Marshallese people in March 1959, 5 years after exposure to fallout radiation, showed that the people had recovered from the acute effects of their radiation exposure and appeared to be generally in good health. The following specific statements can be made in regard to their radiation health status:

1. No illnesses or diseases were found that could be directly associated with acute radiation effects.
2. One case of cancer and three deaths have occurred, but with no direct relation to radiation effects.
3. Fertility does not appear to have been affected. The incidence of miscarriages and stillbirths appears to be somewhat higher than in the unexposed Marshallese, but a deficiency of vital statistics precludes definite conclusions as to whether or not this is a radiation effect.
4. Suggestive evidence of slight lag in growth and development of exposed children noted previously is being reevaluated on the basis of better age data obtained during the past survey.

5. Blood platelet levels are within the normal range but somewhat below those of the unexposed population.

6. Only 12 cases show residual changes in the skin from beta burns. None show any evidence of cancerous change.

7. Possible late effects of radiation such as shortening of lifespan, premature aging, increased incidence of leukemia and malignancies, increased incidence of degenerative diseases, opacities of the lens, and genetic changes have not been observed.

8. The original body burdens of internally absorbed fission products appears to be too low to have produced any acute or long-term effects.

9. The return of the people to the slightly contaminated island of Rongelap has caused some increase in body burdens of cesium 137, zinc 65, and strontium 90. However, the levels are far below the accepted maximum permissible dose and it is not believed any untoward effects will result.

In view of the limited knowledge of the late effects of radiation in human beings, it is considered essential that medical surveys of the Rongelap people continue to be carried out in order to detect and treat immediately any possible further effects of radiation that might develop. Though body burdens of radioactive isotopes are well below the accepted permissible dose levels and no further significant increase in these burdens is anticipated, a close check on these levels during future medical surveys is indicated.

(Whereupon, at 12:30 p.m., the committee recessed, to reconvene at 2 p.m., the same day.)

AFTERNOON SESSION

Representative HOLIFIELD. The committee will be in order.

Our first witness will be Dr. Gordon Dunning of the Division of Biology and Medicine of the AEC. Dr. Dunning will present a short summary of the effects of injection. We will accept his detailed statement for the record, and insert it at the end of his testimony.

Representative HOLIFIELD. Dr. Dunning, the Chair wishes to apologize for the necessity of asking you to summarize your testimony. As you can see, we are running late. We are going to have to carry over some of our witnesses until Friday morning. In the morning we plan to start on article X of the outline, which will have casualty estimates, human beings in the United States, and article XIII. We will try to cover that on Thursday. If we fail to get to some of the witnesses between now and then, we are going to have to carry over. We are running behind, and we have made commitments to members and others to have such data as is available on Thursday.

So at this time, Dr. Dunning, we will ask you to proceed.

TESTIMONY OF DR. GORDON M. DUNNING,[1] DIVISION OF BIOLOGY AND MEDICINE, ATOMIC ENERGY COMMISSION

Dr. DUNNING. Mr. Holifield, in my written testimony I have covered the subject of ingestion, what organs are most greatly affected, the relative amount of exposure to these organs, and the possible biological effects. I will summarize the principal statements in this written record.

[1] Date and place of birth: September 11, 1910; Cortland, N.Y. Education: State Teachers College, Cortland, N.Y., 1929–33; New York University (6 weeks), 1933; State Teachers College, Cortland, N.Y., 1934–36; M.S. (Sci. Edu..), Syracuse University, 1941; doctor of education, 1948. Work history: Teacher, Middletown, N.Y., 1937–41; U.S. Army (lieutenant colonel), 1942–46; instructor, New York Agricultural and Technical Institute, Alfred, N.Y., 1947–48; teacher, Phy. and Phy. Sci., Indiana, Pa., 1948–51; AEC, Biophysics Ren. Anal. Div. B. & M., 1951–53; AEC, Biophysicist, Division of Biology and Medicine, 1953–55; AEC, Radiation Effects Specialist, Division of Biology and Medicine, 1955—.

The organ of principal concern is the gastrointestinal tract, that is, the stomach and the intestines. This may seem somewhat peculiar because there has been so much discussion about dosage to bones from strontium in the worldwide fallout.

Here we are talking about early fallout and relatively high activity where the strontium is only a very small part of the total activity. So you may picture it as more or less a mechanical operation of the ingested fallout material passing through the stomach and through the intestines, and in doing so, irradiating these organs.

Also, an organ of concern is the thyroid because in fallout material there are various isotopes, some of which are isotopes of iodine. These will concentrate in the thyroid.

The third organ is that of bones. On the chart that we have set up there, we give you a quick picture of the relative doses to the adult thyroid and intestines, stomach, and bones. We have taken arbitrarily the dose to the lower large intestine as being one. That is, whatever material that is ingested gives one unit of dose to the lower large intestine, and then corresponding doses will be delivered to the other organs.

You will note that thyroid may receive something like twice the dose of the lower large intestine.

Representative HOSMER. That is just for comparative purposes as between the various organs?

Dr. DUNNING. That is right. The question is, of course, what is the absolute dose. This I would like to hold, with your permission, until we get to the actual analysis of the attack in this problem.

Now we can relate these kinds of effects to the doses that might be expected from the attack as envisioned. The last chart gives some possible effects. I would like to emphasize I am acting as a reporter here. These are not my data. They have been collected by many scientists over many years. They are also very rough estimates and I am sure you will find differences of opinion among scientists.

Very roughly, in terms of the gastrointestinal tract, a few hundred doses, would cause immediate effects, such as nausea. Something like a thousand or over dose tumor production. And not too much greater, 1,500 or 2,000 rad dose, causing serious damage to the intestines, survival being threatened.

Representative HOLIFIELD. Will you, at this time, give us a layman's explanation of the difference between rad and rem?

Dr. DUNNING. A rad is a physical unit describing the amount of energy absorbed. When 100 ergs, and that is a unit of energy, are absorbed per gram of tissue, then you have received one rad of dose. A rem is a unit somewhat comparable. It tries to take into account the difference of biological effects of different radiations. For example, alpha rays would be more biologically damaging per unit of energy delivered. How much more damage depends on several factors but mainly on what is called ionization.

As a particle or ray passes through the tissue, it will disrupt the atoms and the more it disrupts the atoms then we say it is more biologically effective. Alpha particles and fast neutrons will be more biologically damaging even though they deliver no more actual energy.

Representative HOLIFIELD. We should not confuse rad with roentgen?

Dr. DUNNING. In the purer sense, no. Actually it doesn't make too much difference, I think, in trying to have a layman understand what is happening. I have frequently interchanged rad and roentgen. I know that some of my colleagues perhaps won't agree with this, but for a layman I don't think it violates the understanding.

Representative HOLIFIELD. Then we can assume, when you talk of rads in this instance, you are talking about the same number of roentgens?

Dr. DUNNING. Yes.

Representative HOLIFIELD. In an approximate sense. There may be a variation. But in order not to be confused any more than we are we will consider them as being approximately the same.

Dr. DUNNING. Yes, sir; I will.

Representative HOSMER. And your chart applies not to a general dosage but a dosage to a particular organ?

Dr. DUNNING. That is correct. In the first column is the gastrointestinal tract—I was thinking principally there of the lower large intestine. The second column, the thyroid, and starting at the top you will note that it really takes tens of thousands of rads or roentgens to damage an adult thyroid. It is true that children's thyroids are probably more sensitive and there is some question that perhaps in the range of a few hundred roentgen dose a few percent of those children might develop cancer of the thyroid. This may be questioned because these children were treated for an ailment to begin with; secondly, these were external X-rays, whereas we are now talking about doses to the thyroid from the iodine being deposited internally. And there may be a difference.

Representative HOLIFIELD. Would you clarify for the record what you mean by a few hundred roentgens, or a few hundred rads? Can you be specific as to the number that you think would damage a child's thyroid?

Dr. DUNNING. I can quote to you, sir, from the National Academy of Sciences report, and others, where something of the order of 200 roentgens might be carcinogenic to a few percent of the children so exposed.

That was the data that I mentioned a while back. It was based on these perhaps unique population of children that were being treated for disorder of the thymus gland.

Representative HOLIFIELD. Again you used the word "carcinogenic." What do you mean by that?

Dr. DUNNING. Cancer production.

Representative HOLIFIELD. That is just what I am trying to get on the record, because there will be a lot of laymen reading this record. Is it not also true that your thyroid can only absorb so much and then it throws it off? In other words, it does not accumulate to the extent that the other tissues of the body do.

Dr. DUNNING. In terms of iodine, the iodine will be selectively deposited in the thyroid and there will be a rate of elimination peculiar to that particular organ. If I follow the question correctly, sir, there is nothing unique about this. The thyroid throws it off more or less as any other organ. Each organ has its own rate of elimination of these isotopes.

Representative HOLIFIELD. Then the rate of elimination in the thyroid will not affect materially the damage that would be done.

Dr. DUNNING. Some will be eliminated, certainly. But the biological elimination is relatively slow compared with the actual radiological decay of the iodine itself.

The last column, that of bones—and in this problem of early fallout and early ingestion the bones will probably not be the major problem but one which has to be considered to complete the story.

Leaving it with that, sir, I would like to say again that tomorrow when we get into the actual attack pattern we will take these types of effects and relate them to what might happen in your fallout pattern.

Representative HOLIFIELD. Thank you very much. We are glad you will have an opportunity to be back with us and go into more detail on some of the actual physical effects.

Dr. DUNNING. Thank you, Mr. Chairman.

(Dr. Dunning's full statement follows:)

BIOLOGICAL EFFECTS OF A NUCLEAR ATTACK

Gordon M. Dunning
Chief, Radiation Effects of Weapons Branch
Division of Biology and Medicine
U. S. Atomic Energy Commission
Washington, D. C.

SUMMARY STATEMENTS

From the point-of-view of the nation receiving the attack

1. Although it is not a part of this study, the conclusion should be stated that the dominant hazard from a nuclear attack would be the casualties resulting from the blast, heat, immediate nuclear radiation and early deaths from large radiation doses from the fallout.

2. Since time did not permit complete analyses of this attack for all the areas of the United States having different degrees of contamination, an area was selected for consideration having an assumed fallout of two kiloton per square mile. From estimates made for this area, one may extrapolate downward for lesser contaminated areas (or upward for higher contaminated areas).

In this exercise, about 1 - 2% of the country has a greater contamination than two kilotons per square mile. Theoretically, a uniform contamination of the whole United States to two kiloton per square mile would require an assumed attack about 8 - 10 times larger, due to overlapping fallout patterns. Of course, complete uniformity would not exist but the areas with heaviest fallout in general probably would be those with the greatest population densities.

3. The following estimates apply only to an area having a fallout of two kilotons per square mile. In this attack, areas of this level of contamination or larger would encompass 1 - 2% of the country. The remainder of the United States would have lesser degrees of contamination with some areas being only very lightly contaminated.

a. The second major potential hazard would be from intake of radioisotopes in food and water, under the attack conditions of surface bursts. (Doses to the gastrointestinal tract from the gross fission products and doses to the thyroid from radioisotope of iodine). Unrestricted consumption of exposed foodstuffs and crops would seriously threaten the lives of all survivors of the initial attack. A very large percentage of the animals used as a food source would be killed by the external gamma radiation and the intake of contaminated crops in this area. Of course, essentially all milk supplies will be lost and even if the cows survived long enough to give some milk it would not be safe to drink because of the radioiodine in it.

The gross fission product activity on one square foot at one week (for example) after the fallout occurred, if ingested, might be sufficient to cause death to adults or children due to irradiation of the gastrointestinal tract. Thus, exposed foods would be suspected of being too highly contaminated for consumption over periods of many weeks or even months. Since this contamination would be on the surface of the foods much of it might be washed off.

b. Possibly 5 - 10% of the surviving population might develop leukemia or bone cancer. Any such estimate is strongly a function of the assumed external gamma irradiation received - an assumption that depends on many variables including the availability of, and indoctrination to use, shelters.

c. Only crude estimates can be made as to life shortening. It has been estimated here to be about 10% or five years. Again, this is

strongly a function of the assumed dose from external gamma irradiation.

d. It has been estimated that all genetic defects may be increased by a factor of about 1.3 (130%) or less for the first generation with decreasing effects in succeeding generations.

4. For sake of calculations, radiation doses from different isotopes have been considered separately as has their biological effects. This is an oversimplification leading to underestimation of the total impact on man. Very little is known about the human biological responses under the conditions of radiation exposure postulated here. In addition to the uncertainties of estimating individual responses to individual sources of radiation, there are the added uncertainties as to the responses from multiple types of exposures. Further, these exposures will occur under conditions of great emotional and physical strain. Anxiety, fatigue, exposure to the weather, disease, lack of adequate diet, etc. would most likely lead to aggravating the effects. In addition to the more obvious responses of leukemia, bone tumor and life shortening would be the more subtle degenerative effects such as lowering of capacity to work and resistance to disease.

5. The potential external gamma radiation doses described by others at these Hearings, together with estimates made here of the potential contamination of the environment including foodstuffs, point clearly to the benefits of home shelters adequately stocked with food and water supplies to last several weeks or more. Any centralized stores of food would eventually be distributed, but for planning purposes an early distribution could not be relied upon.

From the point-of-view of the "worldwide" contamination

1. It has been assumed that about 75% of the fallout injected into the stratosphere at the latitudes of United States and U.S.S.R. will eventually be deposited in a band between 30° - 60° North latitude. The values given below for this band thus are maximum in terms of "worldwide" effects. Within the 30° - 60° band higher than average values would be expected near the mid-line (45° N) and lower than average nearer the 30° - 60° latitudes. Probably less than 10% of the fallout will be deposited in the Southern Hemisphere, and the remaining 15% distributed over the rest of the Northern Hemisphere.

2. The following estimates apply to the average for the 30° - 60° N Zone:

a. The I^{131} could deliver the greatest dose to any single organ (children's thyroid) possibly being in the range of several hundred to over a thousand rads, although there is a large uncertainty factor in the estimate. Milk as a food item should be avoided until the iodine activity levels dropped to acceptable limits, or canned or powdered milk (prepared before the fallout occurred) should be substituted.

b. The production of leukemia and bone tumors in the surviving population might range from zero (assuming a threshold of 400 rem) to about 1.4×10^{-2}%. (In areas of the world where milk is not the main source of calcium this percentage might rise to about 4.8×10^{-2}%.

c. A crude estimate is made that the exposures postulated here might result in life shortening of a few to several days.

d. The genetic effects might be to increase all genetic defects by about 0.3% or less for the first generation with decreasing percentages in succeeding generations.

BIOLOGICAL EFFECTS OF A NUCLEAR ATTACK

Gordon M. Dunning
Chief, Radiation Effects of Weapons Branch
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Washington, D.C.

I. SCOPE OF THIS PAPER*

The principal factors involved in a study of direct biological effects of a nuclear attack on man are:

A. Shorter-Term Hazards

1. Immediate blast, thermal, and radiation effects - not considered in this paper.

2. For the first months following the attack:

a. External gamma radiations.

Relatively large doses resulting in lethality -- not considered in this papar.

b. External beta radiation -- not considered in this paper.

c. Internal irradiation of the thyroid and of the gastro-intestinal tract by ingestion of contaminated food and water.

*In the time available to prepare this paper, full consideration has not been given to the recognized factors, and additional relevant factors may have been omitted. It is hoped, however, the paper does put the potential effects in perspective. For purposes of calculation, rather precise values and methods have been used in estimating the biological effects. This might imply a degree of knowledge and understanding that does not in fact exist.

This paper is based on the assumed attack suggested for these Hearings, i.e. 1453 megatons (total yield) on United States, 2500 megatons on the Northern Hemisphere outside the continental United States, one-half of the total yield being fission and one-half fusion and all surface bursts. Attacks larger and smaller may be postulated with corresponding changes in estimated biological effects.

B. <u>Long-Term Hazards</u>.

1. Production of leukemia and bone tumor by:

    a. External gamma radiation.

    b. Internal emitters, especially those of Sr^{90} and Cs^{137}.

2. Life shortening.

3. Genetic effects.

II. EFFECTS IN THE UNITED STATES*

A. General. With the assumed attack suggested for these Hearings, the fallout will not be distributed anywhere near uniformly over the United States. To make a rather complete picture of the environmental contamination and estimates of resultant biological effects would require extensive analyses of several different situations as might exist in the United States, as well as any interrelationships among them. Since this was not possible in the available time, an area of relatively heavy fallout (2 KT per square mile) has been considered here. From the estimates made for this area one may extrapolate downward for lesser contaminated areas (or upward for higher contaminated areas). In this attack, areas of this level of contamination or larger would encompass 1 - 2% of the country. The remainder of the United States would have lesser degrees of contamination with some areas being only very lightly contaminated.

In this exercise, about 1 - 2% of the country has a greater contamination than two kilotons per square mile. Theoretically, a uniform contamination of the whole United States to two kiloton per square mile would require an assumed attack about 8 - 10 times larger, due to overlapping fallout patterns. Of course, complete uniformity would not exist but the areas with heaviest fallout in general probably would be those with the greatest population densities.

There may be significant uncertainties in estimating the degree of surface contamination (gross beta activity, strontium-90, cesium-137, etc.) based on external gamma readings. Previous estimates have indicated that 1 megacurie

*To the values for effects estimated in this section should be added those from the fallout common to all areas in the 30° - 60° North latitude band. However, these added values are relatively small compared to those estimated for a local heavily contaminated area considered here.

(gamma activity) per square mile would result in about 4 roentgen per hour 3 feet above an infinitely flat plane.[1] Newer estimates[2] [3] [4] indicate not only more activity disintegrations per minute per kiloton of fission (470 megacuries versus 300 megacuries at H + 1), but also the emission of a large number of photons per disintegration and a somewhat higher energy photon. On the basis of depositing the fission product from one kiloton of fission on one square mile, the newer estimates indicate about 2-1/2 times the gamma dose rate at three feet above an infinite plane at H + 1 than did the previous calculations. In addition, fractionation of the isotopes, reduction of gamma dose rates due to irregularities in the terrain and the presence of any induced activities need to be considered.

One must be concerned with estimating a reasonable "activity balance", i.e., many studies have taken gamma dose rate readings from existent fallout patterns and calculated back to determine what percentage of the total activity produced was accounted for in the "local" fallout. The newer estimates of gamma dose rates would yield a significantly lower percentage of the total activity falling "locally."

In the light of these uncertainties the following conversion factors have been assumed here:

2 KT (fission) per square mile ----->

4,000 r/hr (γ) $\pm$ 40% at H + 1 (theoretical infinite flat plane)

800 megacuries (β)/mi^2 at H + 1

200 curies Sr^{90}/mi^2 (assuming no fractionation)

400 curies of Cs^{137}/mi^2 (assuming no fractionation)

2×10^5 curies I^{131}/mi^2

B. Irradiation of Thyroid and Gastrointestinal Tract. The potential threat to survivors in this heavy fallout area could be considerably greater from gross fission products in food and water (irradiation of the gastro-intestinal tract) and from radioisotopes of iodine (irradiation of the thyroid) than from other internal emitters. Since both sets of these isotopes (gross fission products and radioisotopes of iodine) decay relatively rapidly the actual casualties would be strongly dependent upon the ingestion of contaminated foods and water during the months immediately following an attack. Quantitative estimates of the percentage of casualties from these internal emitters have not been attempted here. It would appear, however, that unrestricted ingestion of exposed foods from these areas for the immediate several weeks following the fallout could be lethal to a high percentage of the population. From this, one can extrapolate the casualty percentages downward to the extent that one wishes to postulate the state of preparedness, i.e. the stockpile of packaged foods and the efficacy of whatever decontamination measures are instituted.*

* It is thought that intake by inhalation would be very significantly less than by unrestricted ingestion of food and water. However, this factor (inhalation) should be studied further and also considered under the premise that relatively uncontaminated food and water were available.

Iodine-131

1. 2 KT/mi^2 -----> 2 x 10^5 curies I^{131}/mi^2

   -----> 7.7 x 10^4 μc I^{131}/M^2

2. Based on Windscale experience

   1 μc I^{131}/M^2 -----> 0.1 μc I^{131}/liter of milk[5]

   For one liter of this milk -----> 2 rad dose to infant's thyroid.*

   For continuous consumption of milk from cows grazing on pasture until I^{131} activity essentially zero -----> 22 - 44 rad dose.*

3. Arithmetically -

   (7.7 x 10^4) (22-44) -----> (1.7-3.4) x 10^6 rads total dose to thyroid of children.

4. Based on data from nuclear weapons tests, the cow's thyroid might theoretically receive a dose two orders of magnitude higher than the numan.[6]

   Actually, of course, the external gamma exposure and the dose to the cow's digestive organs would guarantee its death. If milk were obtained before its death there might be enough I^{131} activity in a single pint of milk to completely destroy the infant's thyroid.

   (7.7 x 10^4) (1-2 rads) -----> (7.7-15) x 10^4 rads

The short-lived isotopes of radioiodine could contribute more dose to the thyroid than does I^{131} for the first day or so, but their activity would decrease rapidly with time.[7] Milk as a food item should be avoided until the iodine activity levels dropped to acceptable limits, or canned or powdered milk (prepared before the fallout occurred) should be substituted.

5. If one assumes all contaminated milk is eliminated from the diet there remains the general I^{131} contamination of the environment including exposed foods and water.

The principal potential source of intake of the I^{131} would be leafy vegetables and other similarly exposed foods. This I^{131} contamination would be reduced by washing the foods, since the water supply would be expected to contain less I^{131} activity due to dilution factors. However, the reduction would have to be considerable since a single intake of I^{131} from one square meter of surface during the first week after the fallout occurred might produce a thyroid dose of more than 10^5 rads to the adult thyroid. It is not being postulated here that persons normally lick over a square meter of surface, but it illustrates the very heavy contamination that might exist in the environment, and that prevention of entry of significant amounts into the body would be a serious consideration.

6. Based on radiological decay only, it would require about 80 days for the I^{131} activity to decay by a factor of 1000. Even considering weathering effects it is doubtful if pasture lande would be useable by then, since doses in the order of a few hundred rads to the infant's thyroid may be carcinogenic.(8)

Thyroid Dose From Continuous Intake of I^{131} at a Daily Rate Decreasing Proportionally to the Radiological Decay

Assumptions

1. An infant will drink 1000 milliliters of milk per day from the same source.
2. The mass of the infant's thyroid is two grams.
3. Thirty percent of the ingested I^{131} will be deposited in the thyroid. (This is on the low side. Studies have shown twice this value for some children).(9)
4. The thyroid is uniformly irradiated. (Some areas may receive higher than this "average" dose).

Step 1. Calculate the initial dose rate to produce 1.0 rad total dose to the thyroid.

$$D = \frac{R_o}{(\lambda_r)\ (\lambda_r + \lambda_b)}$$

where D = total dose

R_c = initial dose rate

λ_r = radiological decay constant

λ_b = biological decay constant

$$1 = \frac{R_o}{(8.66 \times 10^{-2})\ (8.66 \times 10^{-2} + 3.85 \times 10^{-3})}$$

$R_o = 7.8 \times 10^{-3}$ rads/day

Step 2. Calculate the uptake of I^{131} by thyroid to produce 7.8×10^{-3} rads/day

$$\frac{x\ (\mu c)\ (2.2 \times 10^6 \times 60 \times 24)\ (d/day/\mu c)\ (0.22)\ (Mev)\ (1.6 \times 10^{-6})\ (ergs)\ (Mev)}{100\ (ergs/gm/rad)\ (2)\ (gms)} = 7.8 \times 10^{-3} \text{ rads/day}$$

$x = 1.4 \times 10^{-3}\ \mu c$

Step 3. Calculate the concentration per liter to result in uptake of 1.4×10^{-3} μc to the thyroid.

(1.4×10^{-3}) $(3.3) = 4.6 \times 10^{-3}$ μc intake to body to result in one rad dose to thyroid

0.1 μc/l = 22 rads (44 rads if 60% uptake is assumed)

<u>For the case of a single intake of I^{131}</u>

$$D = \frac{R_o}{(\lambda_r + \lambda_b)}$$

Thus, 0.1 μc/l -----> 1.9 rads (3.8 rads if 60% uptake is assumed)

Gross Fission Products

1. Accompanying the ingestion of I^{131} would be the other radioisotopes found in mixed fission products. The beta emissions from these isotopes would irradiate tha gastrointestinal tract. Based on unfractionated mixed fission products,* the radiation dose to the lower large intestine would be roughly a factor of two less than to the adult thyroid from I^{131} for intake during the first weeks after the fallout occurred. After this period the relative dose to the intestine from gross fission products would exceed that to the thyroid from I^{131}. The adult intestine is a much more radio-sensitive organ than the thyroid, with 1000 - 2000 rad dose seriously threatening life.[10]

2. Very roughly -

   a. At, say, one week after fallout occurred

      $2\ KT/mi^2$ -----> $5 \times 10^4\ \mu c/ft^2$

   b. Beta activity intake at one week to produce 1 rad to lower large intestine[11]

      -----> 25 μc

   c. Based on above figures -

      If the activity from one square foot of surface were ingested, death would be imminent.

3. Although this paper does not consider directly the effects on livestock, it will be realized that the doses from external gamma radiation in these areas of heavy fallout will essentially guarantee elimination of animals as a major source of food. A quantitative evaluation of the useability of

*This condition might be approached for surface contamination but would not hold for milk contamination due to the discriminatory effect in the cow.

the pasture land is not attempted here but the above figures indicate that the surface contamination on the crops exposed during the fallout would deny their use for months, and in fact probably would require a waiting period until new crops were grown.

C. External Gamma Exposure. Any estimate of the external gamma dose that persons might receive is dependent on several factors such as the intensity and persistence of the gamma field, the availability and effectiveness of shelters, and the indoctrination of the populace to control their movements under extreme conditions of stress.

The time may come when shelters, with adequate shielding properties, will be built into homes and stocked with a food and water supply for prolonged residence times, and the populace properly indoctrinated to cope with extreme emergency situations-- but in 1959 and the immediate future this is not the case in the United States.[*]

It is assumed here, therefore, that under the holocaust of a werfare situation-- the compelling drives for security and food, the extreme tensions from fear and anxiety--would result in persons exposing themselves for the immediate period following the attack to a limit approaching noticeable radiation effects upon themselves. The total radiation dosage would depend also

*Whether this is more nearly true for Russia is not known but such information as contained in Reference 12 suggests the Russians are undergoing more training, albeit some key information on fallout apparently is being withheld and other information deliberately distorted. For example, only the briefest mention is made of high yield nuclear bombs, and for the Hiroshima-type bombs the fallout is shown as extending over only a few city blocks.

on what persons did thereafter, i.e., use of shelters, evacuation from an area of higher contamination to one with lower contamination, decontamination measures initiated, etc. Obviously, there is no one "solution" in the sense of concluding that persons will receive "X" roentgens of exposure. Therefore, for the purpose of illustrating methods of estimating biological effects only, it is assumed here that the surviving population from this area of heavy contamination would receive an average total dose of 500 roentgens. (A higher or lower assumed dose would result in a corresponding change in the effects estimated below). This would be accumulated over a period of time extending beyond one year but the major portion coming in the first weeks.

External Gamma Calculations

Assume:	Total external gamma exposure:	500 r
	Leukemia induction rate:[a]	1.5×10^{-4}%/r-yrs.(13)
	Bone tumor induction rate:[b]	3×10^{-5}%/r-yrs.
	Mean life of surviving population:[c]	35 years
Leukemia:	(500) (35) (1.5×10^{-4}% ----->	2.6%[d]
Bone Tumor:	(500) (35) (3×10^{-5}% ----->	0.52%

(a) It may be questionable to use these induction rates for such high doses, i.e., if the response curve deviates from linearity, a greater response per radiation dose would be expected at high total doses. On the other hand, "Chronic irradiation is appreciably less effective than acute radiation in the induction of these diseases."(14) and "It also appears reasonable to assume that the annual probability of leukemia death continually changes with time and can be expected to progressively decline beyond 10 years post-exposure." (15)

(b) As stated in Reference Thirteen, "At present adequate statistical data are not available for bone tumours or for tumours of other organs to make such estimates of risk." (Mathematical calculations similar to those for leukemia). However, the report does attempt this (p. 42) with a range of estimates for bone tumor production from 5 - 10 times below that for leukemia. A factor of 5 is used here.

(c) Reference Thirteen. Of course, surviving children will have a longer life expectancy and thus a higher probability of leukemia.

(d) For those born after the external gamma levels have decayed very appreciably (after a year or so), the external gamma doses would become correspondingly less, and the internal irradiation (principally from Sr^{90}) would decrease with time. Thus, the incidence of leukemia and bone tumors for those new born would be expected to drop significantly from the values indicated here, and to continue to decrease for each succeeding year's births. (Except recent data (16) indicate that a greater number of children developed leukemia when the mother received abdominal X-rays during pregnancy, and a similar response would be expected under the exposures postulated here).

D. **Strontium-90**

1. General.

   2 KT/mi^2 -----> 200 curies Sr^{90}/mi^2

   Due to fractionation there may be 2 - 3 times less than this for the close-in areas, i.e. 67-100 curies Sr^{90}/mi^2

2. 80 mc/mi^2 -----> 8 S.U. in children (in equilibrium)* (17) or 10 mc/mi^2 ----> 1 S.U. in children. This is based on U.S. diet including milk as a major source of calcium. Use of other foods as a source of calcium would increase the Sr^{90} intake due to less discriminatory factors.(18)

3. Using 200 curies Sr^{90}/mi^2 and conversion factor

   10 mc/mi^2 -----> 1 S.U. at equilibrium.

   20,000 S.U. -----> 20 r/yr to bone marrow**

   -----> 470 r in 35 years (assuming[a] mean life of surviving population in 35 years, and a radiological decay of Sr^{90} in environment and in man).***

4. The above estimates do not consider any decontamination measures, selection of lesser contaminated foods for consumption, or use of foods from lesser contaminated areas. One may assume these factors will reduce the above estimates by whatever degree we wish to postulate the effectiveness of the factors.

* Equilibrium in children might be reached in 2 - 3 years. Equilibrium would be approached in adults only after many years and to this extent calculations overestimate the effect.

** This may be a somewhat low estimate.

*** The biologically available strontium would be expected to decrease naturally with time faster than its radiological decay would indicate, therefore, the assumption used here tends to overestimate the exposure.

Leukemia Production

If a linear response and no threshold is assumed:

1. Assumed induction rate: 1.5×10^{-4}%/r-yr.
2. (9,400)[a] (1.5×10^{-4}%) -----> 1.4% of the surviving population if they lived in this area. (Subject to the qualifications indicated in section General, above).

If threshold of 400 rem -

Exposure to the bone marrow from Sr^{90} is additive to other doses, i.e. gamma radiation from external and internal sources, etc. Estimates of total exposures to the bone marrow made elsewhere in this report as well as the dose from Sr^{90} do exceed 400 rem.

Bone Tumor Production

Based on reasons given above - assume ~0.3%

(a) See calculations below

Where: R_o = initial dose rate to bone marrow (20 r/yr).

t = time (years) after start of irradiation.

λ = radiological decay constant.

$$D_r - yrs = \int_0^{35} R_o \; e^{-\lambda t} \left[35 - t\right] dt$$

$$D_r - yrs = 35 R_o \int_0^{35} e^{-\lambda t} \; dt - R_o \int_0^{35} te^{-\lambda t} \; dt$$

$$= \frac{35 R_o}{\lambda} \left[e^{-\lambda t} \right]_{35}^{0} - R_o \left[\frac{te^{-\lambda t}}{\lambda} + \frac{e^{-\lambda t}}{\lambda^2} \right]_{35}^{0}$$

$$\simeq 9,400 \text{ r - years}$$

E. Other Bone Seekers.

The two other principal bone seeking radioisotopes (strontium-89 and barium-140-lanthanum-140) are not included since they contribute such a relatively small additional dose when intake is considered over a period of time.

RELATIVE DOSES TO THE BONES FROM

STRONTIUM-90, STRONTIUM-89, BARIUM-140-LANTHANUM-140[a]

	Single Intake at D + 1 day			Continuour Intake from 1st day - 35 yrs.[c]
	Relative activity at D + 1 day	Relative dose rate to bone[b]	Relative total doses to bones[b]	Relative total doses to bones
Sr^{90}	1	1	1	1
Sr^{89}	180	100	1.9	0.018
Ba^{140}-La^{140}	1100	320	1.4	0.0033

(a) No fractionation assumed.

(b) Considering relative half-lives, energies and percent uptake to the bones.

(c) Assuming radiological decay of isotopes in the environment.

F. Cesium-137 (external)*

1. General.

$2\ KT/mi^2 \xrightarrow{\sim} 400$ curies Cs^{137}/mi^2

Due to fractionation this may be 2 - 3 times less for the close-in areas, i.e. 133 - 200 curies Cs^{137}/mi^2.

2. External exposure.

Roughly 1 megacurie $Cs^{137}/mi^2 \xrightarrow{\sim} 4r/hr$

$$R = (4 \times 10^{-4})\ (4) \longrightarrow 1.6 \times 10^{-3} r/hr$$

$$D_{35\ yr.} = \frac{38}{7.03 \times 10^{-5}} \left[1 - e^{-(7.03 \times 10^{-5})(365)(35)} \right]$$

$$= 3.20 \times 10^5 \text{ mr}$$

$$= 320 \text{ r per 35 years}$$

3. These calculations are based on an infinitely flat plane and no account is taken of weathering and shielding effects or of decontamination measures. Actual exposures might be as much as an order of magnitude less than the theoretical dose.(13) Based on similar calculations as for Sr^{90} irradiation of the bone marrow and a reduction factor of about 7** for shielding and weathering effects:

Leukemia ~ 0.13%

Bone Cancer ~ 0.03%

* Gamma dose from shorter lived isotopes is included in the section "External Gamma Exposure."

** To simplify calculations this factor is applied starting the first year although weathering effects would not be completed by then.

4. Internal exposure.

a. Intake of Cs^{137} is more a function of the rate of fall than total deposition. This is because Cs^{137} is very poorly absorbed from the soil and the intake is more a function of surface contamination than of foodstuff. Estimates of dose from internally deposited Cs^{137} is quite tenuous. Reference Thirteen suggests the relationship:

10 millicuries of $Cs^{137}/mi^2/yr$ -----> 0.5 - 2.0 mrem year.

Shortly after the attack some 400 curies of cesium-137 per square mile (assuming no fractionation) would fall in the area under consideration. This is a somewhat different situation than the one upon which the above relationship was based, inasmuch as this is a single fallout (the Cs^{137} dribble from the stratosphere and troposphere would contribute relatively little). However, additional dosage will come as the cesium is being eliminated from the body after reaching equilibrium with the intake. Also, with such a heavy contamination in the environment as postulated here, there will be some re-suspension of the cesium after deposition on the ground.

As great, or greater, an uncertainty would be the contribution of the shorter lived isotopes present in the fallout. Time has not permitted an analysis of this factor Whereas, the theoretical external gamma dose from shorter lived isotopes may be 2-1/2 times that of Cs^{137} (see page 27 for further discussion), their absorption into the body is much less. In addition there undoubtedly are other gross fission products that are absorbed into the body yielding a beta whole body dose.

As a crude estimate then, 400 curies/mi^2 Cs^{137} -----> 60 rem dose

shorter lived isotopes - 60 rem dose

b. Since the dose from these internally deposited radioisotopes will be delivered mainly in the first year, calculation will be made as for external gamma radiation:

Leukemia

(120) (1.5 x 10^{-4}%) (35) -----> 0.63%

Bone tumor -----> 0.13%

G. Life Shortening. The range of estimates made of life shortening per roentgen of exposure given in the literature is great. Some of this is due to the different experimental conditions used, i. e., different dose rates, total doses, species and ages of animals, etc.

"When the radiation dose is delivered in a prompt or acute manner, as a single exposure, the percent reduction of life for mice has been shown to be an accelerating function of dose (Sacher, ANL). In other words, as dose increases, the effect increases at a rate greater than would be calculated on a simple direct proportionality or linear hypothesis. This upward acceleration of effect is particularly noticeable in the dose range that produces acute mortality in the first month or so following exposure. It should be noted that the life shortening measures do not include the acute mortality, but are restricted to the animals surviving the acute radiation syndrome."

"For the mouse, a single dose of 100 r shortens life by about 5%, or roughly 30 days in 600. Available data indicate a variable life shortening effect down to 25 r. Below this, the single dose data are uncertain."(18)

Somewhat lower estimates are given in Reference Eight. "Small laboratory animals subjected to irradiation either at high daily rates for short periods or low daily rates for long periods suffer about 7% life shortening per LD_{50} and the effect is proportional to dose, or nearly so, for doses up to about three times LD_{50}. The data for low daily rates and small total doses in the 100 r range are not definitive, there being almost as many showing prolongation, as shortening, of life. While this again is probably due to failure to use sufficient numbers of animals to measure small effects, it leaves to be resolved the possibility that low daily doses actually prolong life, unlikely as this may seem."

For laboratory animals, the percent of reduction of life per 100 r increases as the dose increases (single exposures) with the percentage increasing rapidly as doses approach the LD_{50} region. In the dosage range of about 200-500 r, the reduction is from 2 to 4% per 100 r. There are a few data that indicate that the percent reduction of life span from a single dose is independent of the age of the adult animal, provided there is a sufficient remaining normal life span to permit the shortening effect to be manifest.(19)

Chronic doses (small daily doses for long periods of time) may result in life shortening of some 11% per 1000 r, for accumulated dosage varying from 500 r up to 2000 r or more.(19)

The anticipated exposure to the population from the wartime situation is neither a "single" dose nor "small daily doses for long periods of time." Also, extrapolation from animals data to man is most tenuous but, in general, man has shown a slower rate of recovery. Based on the exposures given here, a crude estimate of life shortening is 10% or 5 years.* If the assumed external gamma exposure is higher, then the anticipated life shortening would be correspondingly higher.

*Since most of the animal data are based on young adults, this would correspond roughly to a 20-year old human with a life expectancy of about 50 years.

H. <u>Genetics</u>[a]

Assume doubling dose ----> 50 r [b] then,

A. Additional tangible defects

$\frac{670^{(c)}}{50} \times \frac{1}{10} \times 2\% \cong$ ----> 2.7% or less[b] of all live births first generation[d]

B. Additional stillbirths and childhood deaths

2-1/2 times tangible defects[19]

(2.5) (2.7%) $\cong$----> 6.7% or less[b] of all pregnancies first generation[d]

C. Additional embryonic and neonatal deaths

5 times tangible defects[19]

(5) (2.7%) $\cong$----> 14% or less[b] of all conceptions first generation[d]

(a) The following estimates generally apply to relatively large populations and therefore would not be so appropriate to the more limited numbers of persons being considered here.

(b) Recent data from Dr. Russell (Oak Ridge) shows less production of genetic defects at lower dose rates by a factor of about four. The above estimates, therefore, may be high.

(c) Total genetic exposure.

(d) With decreasing effects in succeeding generations.

(e) Normal rates today -
2% (of all live births) - tangible defects
5% (of all pregnancies) - stillbirths and early childhood deaths
10% (of all conceptions) - embryonic and neonatal deaths

Carbon-14

1. Assume: 1 M.T. (total yield) ----> 2×10^{26} neutrons (Outside bomb)
   ----> 4.7 Kg C^{14}

   If one-half of neutrons "lost" to ground (i.e. surface bursts),

   then ----> 2.4 kg. C^{14}/M.T.

2. 3953 M.T. (total yield) $\sim$----> 9.3×10^3 kg. C^{14}

3. There are two reservoirs for freshly produced C^{14}:[21]

   4.4% in reservoir A[a] with Tm of 8070 yrs.

   95.6% in reservoir A with Tm of 27.2 yrs.

4. There are 3200 kg. C^{14} normally present in reservoir A[b].

$$\frac{(9.3 \times 10^3)\ (4.4 \times 10^{-2})}{3200} \times 8070 \times 1.5^{(c)} = 1550 \text{ mr}$$

$$\frac{(9.3 \times 10^3)\ (9.6 \times 10^{-1})}{3200} \times 27.5 \times 1.5 = \underline{120 \text{ mr}}$$

   Total 1670 mr or $\sim$1.7r

5. Assuming that transmutations account for roughly the same number of genetic defects as does radiation, [22] then: $\sim$3.4 r "effective" over 8000 years.

6. During the same period of time (8000 years) the dose from naturally occurring radioisotopes in the environment and from cosmic rays might amount to 800 r (assuming no change in the present rate). The effect from C^{14} would not be zero but would not constitute a problem to the same degree as other factors.

(a) The atmosphere, the land biosphere, and humus.

(b) This assumes uniform distribution over the world which may not be too greatly in error for C^{14}.

(c) Yearly dose from C^{14} present in environment.

II. EFFECTS OUTSIDE THE COUNTRIES ATTACKED *

(30° - 60° N. latitude)

A. General

1. It has been assumed here that about 15% of the total activity will be injected into the stratosphere and 5% into the troposphere from surface detonations in the general latitudes of the United States and Europe. (80% falls "locally"). Of the 20% injected into the stratosphere and troposphere, about 70-75% will fall between 30° - 60° North latitude - i.e., an assumed midline of 45° N, a roughly Gaussian distribution with a standard deviation of 10-15°. Probably less than 10% of the activity injected into the stratosphere and troposphere will be deposited in the Southern Hemisphere and the remaining 15% distributed over the rest of the Northern Hemisphere.(22)

2. Thus the effects estimated here for 30° - 60° N. are maximum for the "world wide" effects. Since the fallout has been averaged within the 30° - 60° N. band, there will be areas nearer the midline with higher than average values and areas farther from the midline with lower than average values. Limited time for preparation of this report has not permitted further analyses of the fallout distribution and of population densities.

B. Shorter-lived Activities

1. Iodine-131

a. 2000 M.T. (fission - total in the world) ---> 2.0×10^{11} curies produced

b. (2.0×10^{11}) (0.05) (0.75) = 7.5×10^{9} curies I^{131} in troposphere 30° - 60°N

* Areas outside the countries attacked but immediately downwind will receive heavier fallout than estimated in this section.

c. With radiological half life of 8 days and an assumed half time of residence in troposphere of two weeks -

Total disintegrations -

$$\frac{A_o}{\lambda_r} = 11.5\, A_o$$

Where: A_o = initial activity

λ_r = radiological decay constant

Total disintegrations occurring on the ground -

Where: λ_d = constant for residence time in troposphere

$$\left[\frac{\lambda_d}{\lambda_r + \lambda_d}\right] 11.5\, A_o = 4.2\, A_o$$ or about 36% of disintegrations occur on the earth

d. Since total disintegrations have a direct relation to activity -

The "effective" activity of I^{131} upon deposition on

$$\text{earth surface} = \frac{(7.5 \times 10^9)\,(0.36)}{36 \times 10^6} = 75 \text{ curies/mi}^2$$

$$= 29\ \mu c/M^2$$

e. Based on similar considerations as before

$29\ \mu c/M^2$ -----> 640 - 1280 rad dose to infant's thyroid for continuous consumption of milk.*

* Additional intake of I^{131} could come from surface contamination of other foods. The estimates here are based on an assumed infant's thyroid of two grams. Appreciable intake of other contaminated foods would indicate a diet for an older person and thus a larger thyroid. Other uncertainties in these estimates did not appear to make it feasible to attempt further refinement.

B. Shorter-lived Activities (continued)

2. Gross Fission Products (External gamma)

The external gamma exposure from short lived isotopes depends upon the assumed time of deposition. In the time available, a cursory look was given to the principal gamma emitters - Zr^{95} - Nb^{95}, Ba^{140} - La^{140}, Ce^{144}, and Ru^{103} - Rh^{103}. These were then compared to Cs^{137}. In terms of relative total energy theoretically dissipated from the troposphere fallout, with an assumed time of deposition of about two weeks and extending out to 35 years, these shorter lived isotopes contributed about 6 times that from Cs^{137}. Since it has been assumed that 5% of the Cs^{137} went to the troposphere and 15% to the stratosphere, the total theoretical energy from the shorter lived isotopes amounts to about 1-1/2 times that from all the Cs^{137} (tropospheric and stratospheric). Probably shorter lived isotopes of lesser importance have been overlooked plus the contribution of shorter lived isotopes from the stratospheric fallout should be added. Therefore, it is assumed here that the shorter lived isotopes contribute about 2-1/2 times that of Cs^{137} (see section Cesium-137 below). The estimated theoretical dose would be about 3.5 r. The actual dose may be less by as much as a factor of 10 due to weathering and shielding. A value of 0.5 r is assumed here.

Since a major portion of the doses from these mixed fission products would be delivered in the first year or so, calculations are comparable to these for external gamma radiation.

If no threshold - (12)

Leukemia	(0.5) (1.5×10^{-4}%) (35)	2.6×10^{-3}%
Bone Tumor		5.0×10^{-4}%

If threshold of 400 rem - (12)

No significant number of cases.

C. Strontium-90

1. 2000 M.T. (fission) -----> 2.0×10^2 megacuries Sr^{90} produced

2. (2.0×10^2) (0.20) (0.75) -----> 30 megacuries for distribution

3. $\frac{3.0 \times 10^7}{3.6 \times 10^7}$ -----> 0.83 c/mi^2 *

4. Based on previous considerations:

   0.83 c/mi^2 -----> 83 S.U. in man

   In some parts of the world with different dietary intake of calcium such as the Far East, the strontium units may increase up to a factor of six.(12)

5. Leukemia production:

   If no threshold -

   83 S.U. in man --~-> $5.7 \times 10^{-3}\%$

   If threshold of 400 rem -

   No significant number of additional cases

6. Bone tumor production:

   If no threshold -

   Based on same considerations as before ~ $1.1 \times 10^{-3}\%$

   If threshold of 400 rem -

   No significant number of additional cases

* In addition to the distribution within the 30° - 60° band discussed above, areas with heavier rainfall would be expected to have higher levels of strontium-90 activity.

D. Cesium-137 (external)

1. 2000 M.T. (fission) $\xrightarrow{\sim}$ 4.0×10^2 megacuries Cs^{137}

2. (4.0×10^2) (0.20) (0.75) -----> 60 megacuries for distribution 30° - 60° N

3. $$\frac{6.0 \times 10^7}{3.6 \times 10^7} = 1.7\ c/mi^2$$

4. Based on previous considerations:

   $1.7\ c/mi^2$ $\xrightarrow{\sim}$ 1.4 r per 35 years theoretical maximum dose

   $\xrightarrow{\sim}$ 200 mr "actual" dose/35 years - assumed

5. Based on similar calculations as for Sr-90 irradiation of the bone marrow:

   If no threshold -

   Leukemia 5.7×10^{-4}%

   Bone tumor 1.1×10^{-4}%

   If threshold of 400 rem -

   No significant number of cases

E. Cesium-137 (internal)

1. Based on previous considerations:

   $1.7\ c/mi^2$ Cs-137 plus shorter lived isotopes $\xrightarrow{\sim}$ 500 mr

   If no threshold -

   Leukemia ~ 2.7×10^{-3}%

   Bone Tumor ~ 5.0×10^{-4}%

   If threshold of 400 rem -

   No significant number of cases.

F. Life Shortening

Estimations of life shortening under the conditions assumed here require the extrapolation down to the one roentgen range which would be most uncertain. Only a guess can be made that such an exposure might shorten lives by a few to several days.

G. Genetics

Assume doubling dose -----> 50 r [a]

Then,

1. Additional tangible defects

$\frac{1.5^{(b)}}{50} \times \frac{1}{10} \times 2\%$ -----> $6.0 \times 10^{-3}\%$ or less[a] of all live births, first generation[c]

2. Additional stillbirths and childhood deaths

2-1/2 times tangible defects

$(2.5)\ (6.0 \times 10^{-3}\%)$ -----> $1.5 \times 10^{-3}\%$ or less[a] of all pregnancies, first generation[c]

3. Additional embryonic and neonatal deaths

5 times tangible defects

$(5)\ (6.0 \times 10^{-3}\%)$ -----> $3.0 \times 10^{-2}\%$ or less[a] of all conceptions, first generation[c]

(a) Recent data from Dr. Russell (Oak Ridge) shows less production of genetic defects at lower dose rates by a factor of about four.

(b) Total genetic exposure (effective rads).

(c) With decreasing effects in succeeding generations.

(d) Normal rates today in United States:
2% (of all live births) - tangible defects;
5% (of all pregnancies) - stillbirth and early childhood defects;
10% (of all conceptions) - embryonic and neonatal defects.

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Criteria for Establishing Short Term Permissible Ingestion of Fallout Material

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THE CRITERIA for establishing permissible ingestion of radioactive fallout material under emergency conditions for several weeks following a nuclear detonation are dependent primarily on exposures to the,

a. gastrointestinal tract from the gross fission product activity,

b. thyroid from the isotopes of iodine and,

c. bone, principally from Sr^{90}-Y^{90}, Sr^{89}, Ba^{140}-La^{140}.

I. Doses to the Gastrointestinal Tract

The following principal assumptions are used in calculating the doses to the gastrointestinal tract of adults:

a. The calculations are based on the methods contained in reference one.

b. The fallout material is 90 per cent insoluble. (See IV. Discussion below).

c. The activity decays according to the principle of $(\text{time})^{-1.2}$.

d. The energy delivered is all derived from the beta emissions, having a mean energy of 0.4 Mev when in the lower large intestine. (See Graph 1)*

e. The total daily consumption of food and water is 2200 grams or milliliters.

The method of calculation is according to the following equation:

$$\frac{(\text{Total number of disintegrations occurring in organ})\ (\text{Energy of emissions})\ (8.0 \times 10^{-9})}{\text{Mass of Organ}} = \text{Dose (rads)} \quad (1)^*$$

The number of disintegrations taking place in the organ may be calculated according to equation two:

$$\text{Total number of disintegrations} = 5A_a\, t_a^{1.2}[t_a^{-0.2} - t_b^{-0.2}] \quad (2)$$

Where: A_a = number of disintegrations per unit time at time "a" after detonation.

t_a = time "a" after detonation.

t_b = time "b" later than "a".

* The rad is the unit of absorbed dose equal to 100 ergs per gram.

$$\frac{1.6 \times 10^{-6}\ (\text{ergs/Mev})\, 0.5\ (\text{proportion of total energy to gastrointestinal tract})}{100\ (\text{ergs/gm-rad})} = 8.0 \times 10^{-9}$$

One of the more useful forms for the criteria would be in units of permissible concentrations at time of intake. This will somewhat complicate the calculations since there will be a decrease in activity as the material passes along the gastrointestinal tract. When such calculations are made according to the above assumptions and equations, it may be seen that the critical organ is the lower large intestine except for the first hours immediately following the detonation. (Table I shows the relative doses to parts of the gastrointestinal tract as a function of time.) Therefore, Graph 2 is based on the activity at time of ingestion to produce one rad of dose to the lower intestine.

For example, Graph 2 shows that if about 48 microcuries are ingested on the 24th hour after detonation, the lower large intestine may receive one rad of radiation dose. This was calculated in the following manner.

Step 1. Determine the total number of disintegrations in the lower large intestine necessary to produce 1.0 rad.

From equation (1)

$$\frac{(\text{Number of disintegrations})\ (0.4)\ 8.0 \times 10^{-9}}{150} = 1$$

Number of disintegrations $= 4.7 \times 10^{10}$

Step 2. Determine the activity at time of intake to produce 4.7×10^{10} disintegrations within the large intestine.

$$\frac{4.7 \times 10^{10}}{0.9} = 5.2 \times 10^{10}$$ disintegrations intake required (assuming 10% solubility).

From equation (2)

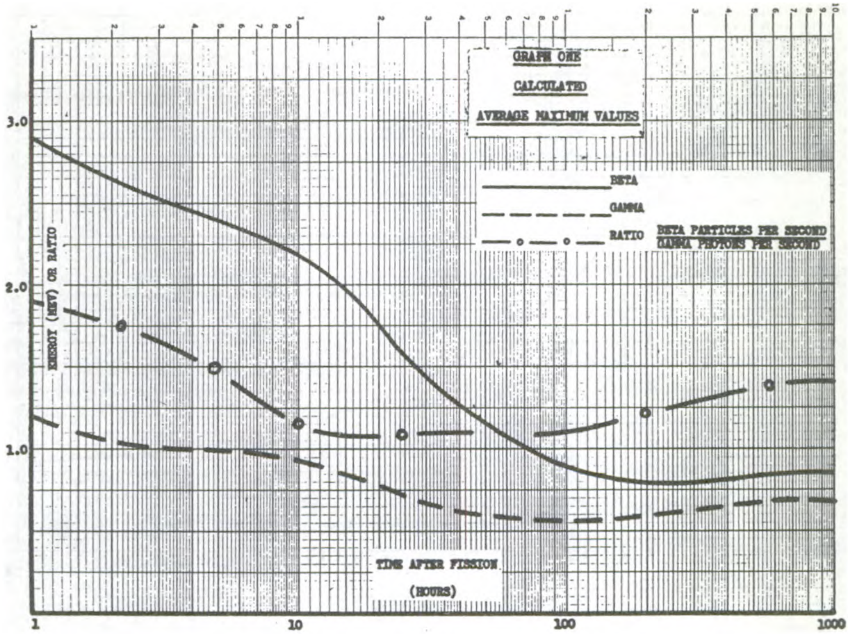
$$5.2 \times 10^{10} = (5)\ (A_{37})\ (37^{1.2})\ [37^{-0.2} - 55^{-0.2}]\ ^*$$

$A_{37} \cong 3.7 \times 10^{8}$ d/hr.

$A_{24} \cong 6.2 \times 10^{8}$ d/hr.

$A_{24} \cong 47\ \mu c$

* If the time of intake is the 24th hour, then the start of irradiation of the lower intestine is 24 + 13 = 37th hour, according to reference one.



GRAPH 1

TABLE I

Relative Doses to Gastrointestinal Tract from Ingestion of Fallout Material

	Time After Detonation That Ingestion Occurs		
	1st Hour	1st Day	Limiting Case*
Lower Large Intestine	1.0	1.0	1.0
Upper Large Intestine	1.3	0.71	0.49
Small Intestine	0.26	0.054	0.03
Stomach	0.86	0.063	0.03

* Based on assumption that there is no significant decrease in activity during time of passage through gastrointestinal tract. After a week following detonation the decrease in activity between the stomach and the midpoint of time in lower large intestine is within about 20% of this condition.

Graph 2 has been used in estimating radiation doses to the lower large intestine for prolonged periods of ingestion (Table II). The following calculations are illustrative for the period of 24th to the 120th hour (start of intake at the beginning of the 2nd day after detonation for a duration of four days).

Step 1. Determine the number of microcuries at time of ingestion to produce 1.0 rad to the lower large intestine.

From Graph 2 take the mid point of intake period (72nd hour) $\rightarrow$ 31 μc. (This is obviously an approximation since the exact times of intake during the four-day period will be unknown.)

Step 2. Determine the activity at time of intake.

From equation (2)

$31 = 5A_{24}\, 24^{1.2}\, [24^{-0.2} - 120^{-0.2}]$

$A_{24} \cong 0.94\ \mu c/hr$

Since there is assumed a 2200 ml/day intake

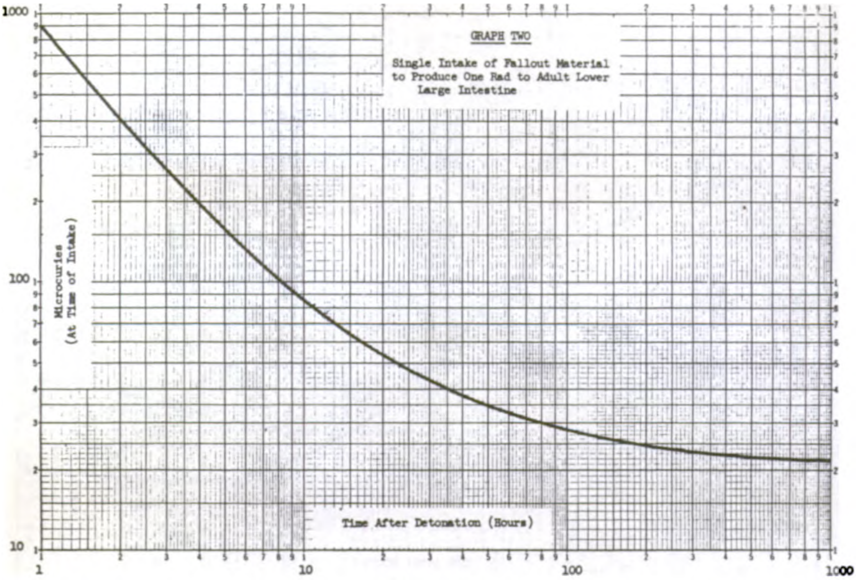
$$0.94 \times \frac{24}{2200} \cong 0.010\ \mu c/ml \text{ or gm}$$

II. Doses to the Thyroid

The following principal assumptions are used in calculating the doses to the adult thyroid from intake of activity from fallout material:

a. The percentages of the isotopes of iodine in mixed fission products are according to Hunter and Ballou.[3]

b. Twenty percent of the ingested I^{131} reaches the thyroid.



GRAPH 2

c. The mean energy is 0.22 Mev.

d. The thyroid weight is 20 grams. (See IV. Discussion below)

e. The percentages of shorter-lived isotopes of iodine that reach the thyroid and their doses are according to reference four.

The method of calculation of doses to the thyroid is illustrated by computing that amount of intake of fission products at the 48th hour to produce 1.0 rad.

Step 1. Determine the dose rate on the day of intake of I^{131} to produce 1.0 rad to the thyroid.

$D = (R/\lambda_e)$

Where: D = dose (1.0 rad)

R = dose rate on initial day

λ_e = effective decay constant (radiological and biological)

$1.0 = (R/0.09)$

$R = 0.09$ rads/day

Step 2. Determine the number of microcuries of I^{131} to produce 0.09 rad/day

$$\frac{X(\mu c)(2.2 \times 10^6)(60 \times 24)(1.6 \times 10^{-6})(0.22)}{(100)(20)} = 0.09$$

$X = 0.16\ \mu c$ to thyroid or

$(0.16)\ (5) = 0.80\ \mu c\ I^{131}$ ingested

Step 3. Determine relative doses from I^{131} and I^{short} according to Graph 3.[4]

TABLE II

Approximate Fission Product Activities (Microcuries per Milliliter of Gram $\times 10^2$) to Produce one Rad Dose to Lower Large Intestine*

Duration of Ingestion (Days)	Start of Intake (Days after detonation)							
	1 (1st Hour)	2 (24th Hour)	3	4	5	10	15	20
1	35	2.5	1.9	1.7	1.4	1.1	1.1	1.0
2	24	1.7	1.1	0.89	0.81	0.62	0.57	0.53
3	15	1.3	0.82	0.65	0.56	0.41	0.40	0.37
4	13	1.0	0.65	0.53	0.46	0.33	0.30	0.29
5	12	0.9	0.57	0.44	0.39	0.28	0.25	0.22
10	9.2	0.64	0.40	0.29	0.25	0.17	0.14	0.13
15	7.8	0.53	0.33	0.26	0.21	0.13	0.11	0.097
20	7.5	0.49	0.29	0.21	0.18	0.11	0.089	0.079

* a. Activities computed at start of intake period.

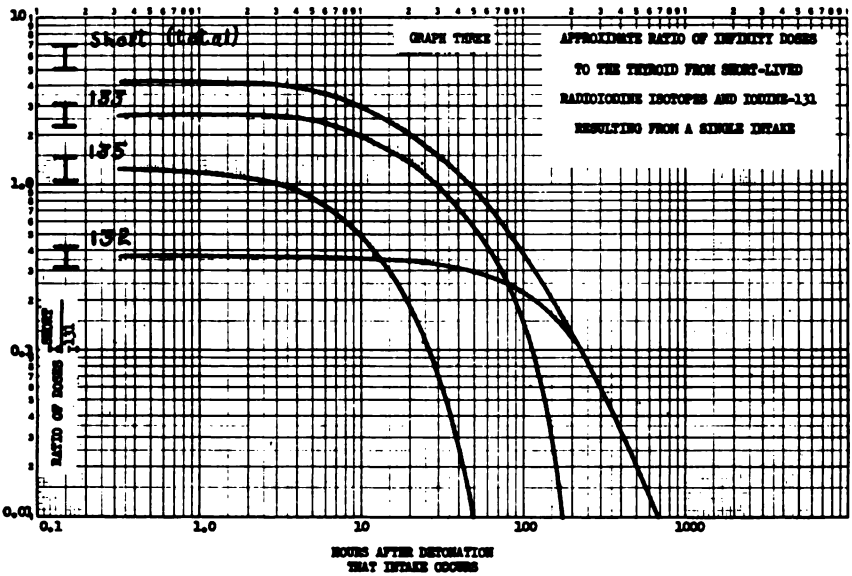
b. Based on intake of 2200 milliliters or grams of water and food per day for adults.

At 48th hour, the relative contribution to total dose from I^{131} and I^{short} is about 1/1.

Therefore, ingestion of 0.4 $\mu c\ I^{131}$ (equivalent) at 48th hour will produce 1.0 rads to thyroid.

Step 4. Determine the number of microcuries of fission products required to yield the required I^{131} activity. At 48th hour, I^{131} constitutes about 2.35% of total activity. Therefore,

$(0.4/0.023) \cong 17\ \mu c$ of fission products.



GRAPH 3

Graph 4 shows the number of microcuries of fission products ingested at times after detonation to produce 1.0 rad to the thyroid.

III. Doses to the Bones

The three principal bone-seeking isotopes of concern are Sr^{90}-Y^{90}, Sr^{89}, and Ba^{140}-La^{140}. Evaluation of these may be made in terms of amount deposited in the bones versus maximum permissible body burdens, or in rads of dose that they deliver after deposition. Since values for maximum permissible body burdens are based on the concept that these will be maintained indefinitely in the body, they are not so valid for Sr^{89} and Ba^{140}-La^{140} when considering short periods of emergency intake.

The following principal assumptions are used in calculating the doses to the bones of adults:

a. The percentages of the isotopes of Sr^{90}-Y^{90}, Sr^{89}, and Ba^{140}-La^{140} in mixed fission products are according to Hunter and Ballou.[4]

b. The percentages of intake of these isotopes that are deposited in the bones, the energies of emissions, and their effective half lives are according to reference five—except for Sr^{90} where a 27.7 year radiological half life is used here.

c. The mass of the bones is 7,000 grams.

The method of calculation of doses to the bones is illustrated by computing the dose from Sr^{89} from the intake of 27 microcuries (See IV Discussion below) of mixed fission products on the 120th hour. Similar calculations were made for Sr^{90}-Y^{90} and Ba^{140}-La^{140} and then the three doses were added for each intake of fallout material.

Step 1. Determine the Sr^{89} to reach the bone.

According to reference 4:

The Sr^{89} content in mixed fission products on the 120th hour is 1.6%.

According to reference 5:

The intake of Sr^{89} to reach to the bones is 25%.

Therefore:

(27) (0.016) (0.25) = 0.108, to the bone.

Step 2. Determine the dose rate to the bones.

With an assumed effective energy of 0.55 Mev (reference 5):

$$\frac{(0.108)(2.2 \times 10^{6})(60 \times 24)(1.6 \times 10^{6})(0.55)}{(100)(7{,}000)}$$

$$= 4.3 \times 10^{-4} \text{ rads/day } \textit{or } 0.43 \text{ millirads/day}$$

Step 3. Determine total dose.

D total $= (R/\lambda e)$

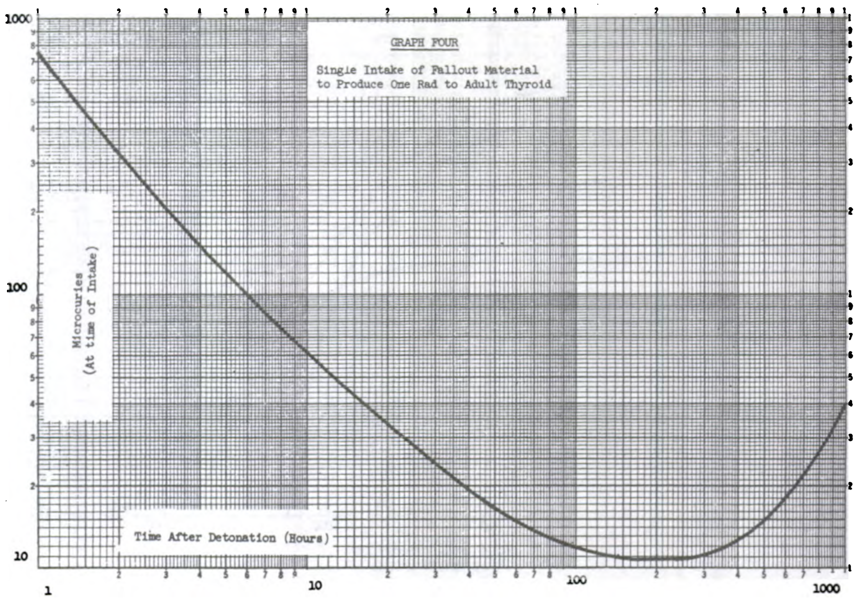
where: R = initial dose rate

λe = effective decay constant

D total $= (0.43/0.0133) \cong 32$ millirads*

* The relative total doses from these isotopes are as follows:

Time of intake	Sr^{90}	Sr^{89}	$Ba^{140}-La^{140}$
24th hour	0.6	1.00	0.6
30th day	1.00	1.00	0.3



GRAPH 4

IV. Discussion

A. Solubility

The solubility of fallout material varies, depending among other factors upon the surface over which the detonation occurred. The fallout material collected in soil samples at the Nevada Test Site has been quite insoluble, i.e. only a few per cent in distilled water and roughly 20–30 per cent in 0.1 N HCl. However, it would be expected that the activity actually present in drinking water supplies would be principally in soluble form. The water collected from a well and a cistern on the Island of Rongelap (Table III) about 21 months after the March 1, 1954 fallout, was found to have about 80 per cent of the activity in the filtrate, but there was an undetermined amount that settled to the bottom. Other data suggest the material to have been about 10–20 per cent soluble in water.

In the event contaminated food is ingested it is possible that the total activity—soluble and insoluble—may find its way into the gastrointestinal tract since at times immediately following a fallout most of this activity probably would come from the surface contamination rather than the soil-plant-animal cycle. There may then follow some solubilizing in the acid stomach with subsequent removal from the tract before reaching the lower large intestine.

TABLE III

Concentrations in Water on Islands in the Pacific and Estimated Gamma Dose Rates at D + 1, Three Feet Above Ground

Date	Location	Gross Fission Product Activity (d/m/ml)
	Rongelap Island (3.5 roentgens per hour)	
D + 2	Cistern	~50,000–75,000
D + 34	"	~5,500
D + 34	Openwell	~2,000
D + 300	Cistern	~3
D + 330	"	~4
D + 600	"	~5.5
D + 600	Openwell	~0.5
D + 600	Cistern (With collapsed roof)	~1.3
	Kabelle Island (19 roentgens per hour)	
D + 330	Ground water	~48
	Eniwetok Island (8.5 roentgens per hour)	
D + 330	Cistern	~25
	Enibuk Island (1.3 roentgens per hour)	
D + 600	Standing water from can, drum, etc.	~1.4

It is assumed for these calculations that (a) 90% of the fallout material is insoluble when computing doses to the gastrointestinal tract, and (b) that the isotopes of iodine, strontium, and barium are all soluble when computing doses to the thyroid and to the bones. These assumptions are probably conservative, i.e. they may overestimate somewhat the radiation exposures.

B. Biological Significance

After the estimation of radiation doses by any procedure the final step is an evaluation in terms of biological effects both for short and long terms.

1. Gastrointestinal Tract

There have been few experiments where the gastrointestinal tract has been exposed in a manner similar to the one assumed here. One experiment[6] indicates lower doses to the intestine than the model proposed in reference 1.

In another experiment,[7] rats were fed 1.0 to 6.0 millicuries of yttrium-90 in a single feeding. Four of the 33 animals died of adenocarcinoma of the colon and additional animals died with acute and chronic ulceration of the colon. A second group of rats was given 0.46, 0.20, or 0.06 mc of Y^{91} per feeding over a period of three months with total accumulated amounts of 31.2, 15.6 and 4.68 mc respectively. Six of the eight animals at the two higher levels died with carcinoma of the colon and no malignancies were observed at the lowest level. The authors made no estimate of radiation doses.

In another experiment,[8] rats were kept alive by the use of parabiosis or para-aminoproprio-phenone either pre or post whole-body irradiation of 700–1000 roentgens. Four of the 21 rats developed tumors along the gastrointestinal tract (one each jejunum, ileum, duodenum, and colon), with four additional animals showing tumors in other organs. However, in comparing gastrointestinal versus whole-body irradiation, the question has been raised as to a possible indirect carcinogenic action in the latter case.[9] By using fast neutrons, lesser doses have been shown to produce an appreciable percentage of intestinal carcinomas in mice, but this is not so relevant to the present discussion of beta exposure.[10]

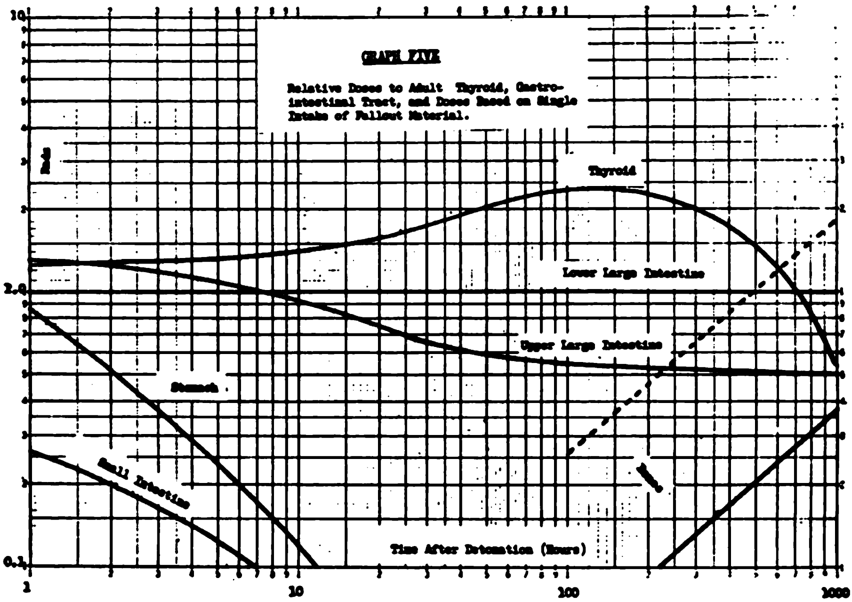
One summarizing statement of the short-term effects stated, "... though the gastrointestinal tract is one of the sensitive systems to ionizing radiation, it also has a most remarkable regenerative and reparative capacity. It takes doses of well over a thousand roentgens to damage the gut permanently in most mammals studied, and it is capable of rapid, dramatic recovery of anatomical and functional integrity with doses in the lethal range."[11] Evaluating the data from dogs exposed to whole-body X-radiation the authors said, "... it is suggested that doses of approximately 1,100 to 1,500 r may represent the upper limit of the possible efficacy of supportive measures in the treatment of the syndrome of acute radiation injury. With greater doses the damage to the intestinal mucosa appears irreparable and of an extent incompatible with life."[12] At the same time, it has been repeatedly indicated that the irradiation of the gastrointestinal tract plays a major role in gross whole-body effects associated with radiation syndrome.[11, 12, 13, 14, 15, 16, 17, 18, 19, 20] In fact one author[13] summarizes several experimental findings, "In producing acute intestinal radiation death, irradiation of any major portion of the exteriorized small intestine alone is almost equivalent to whole-body irradiation . . . ."

Graph 5 suggests the relative doses to the parts of the gastrointestinal tract, from ingestion of fallout material. The available experimental data does not permit a conclusive statement as to whole-body effects to be expected from such ratios of exposures. Most of these experiments are related to the criterion of death, but they do suggest that the major contributory factor to such effects such as nausea and vomiting associated with whole-body exposures of 100–200 roentgens, may be the result of the gastrointestinal reaction. Possibly a few hundred rads to the lower large intestine together with the concomitant lesser exposures to the upper large intestine, the small intestine and the stomach (according to Graph 5) may be in the range where radiation sickness might occur.

2. Thyroid

The study and treatment of disorders of the thyroid gland with radioiodine has led to considerable information on doses and their effects to this organ. (Only a partial list of references is noted.)[21, 22, 23, 24, 25] Whereas these treatments have been principally with abnormal thyroids, much of the information may be extrapolated to normal thyroids for the purposes of this discussion. In addition there are other data based on normal thyroids in patients suffering such ailments as congestive heart failure.[26]

The picture clearly presented is that the adult human thyroid is relatively insensitive to radiation. For example, Freedberg, Kurland, and Herman,[26] report, "... Seven days after administration of 17 and 20 millicuries of I^{131}, which delivered 14,500 and 31,000 rep, respectively, to the thyroid gland, no histologic



GRAPH 5

changes were noted which could be attributed to I^{131}.... Fourteen and twenty-four days, respectively, after administration of 59 and 26 millicuries of I^{131}, marked central destruction of the thyroid gland was noted...." Since the first two patients expired seven days after administration of the I^{131} from pulmonary edema, it does not eliminate the possibility that the destructive changes might have appeared in the thyroid if these patients had survived. However, the evidence from other studies strongly indicates that if any pathological effects were to be noted in the thyroid after an exposure of some 10,000 reps they would be minimal. Likewise, the possibility of serious damage to other organs of the body, such as parathyroids and trachea which are simultaneously exposed to the I^{131} radiations, would be exceedingly small.

On long terms effects, two summarizing statements may be made. "No thyroid neoplasm was found which could be attributed to I^{131},"[108] after doses to normal thyroids running into many tens of thousands of reps and after periods of observation up to more than eight hundred days. "In a series of over 400 patients treated with radioactive iodine at the Massachusetts General Hospital during the past ten years no known carcinoma of the thyroid attributable to this agent has developed. Definite answers to the question of carcinoma formation must await prolonged observation of treated patients."[109] Here the average treatment dose of I^{131} was 10 millicuries and of I^{130} 25 millicuries.

However, significantly lesser doses may be carcinogenic in children.[87] "...It has been suggested that the human thyroid is less radiosensitive than other tissues, such as bone, since after many years of treatment of Graves' disease with radioactive iodine, no cases of resulting carcinoma have been reported. The customary dosages of I^{131} in such cases yield at least 4000 rep to the gland. On the other hand, carcinoma of the thyroid found in children and young adults has almost invariably been preceded by x-ray treatment to the upper part of the body, in amounts such as to yield as little as 200 r to the infant thyroid. It has been estimated that less than 3 per cent of such treated cases yield carcinoma; nevertheless, the data suggest that 200 r is a potentially carcinogenic dose to the infant thyroid. While the possibility exists that the carcinogenic action may be an indirect, hormonal one, it must still be recognized that this, like leukemia, is an instance of significant car-

cinogenesis by less than 1000 rep. It seems likely that the infant thyroid is unduly susceptible, but that the adult thyroid is not...."[illegible]

Table II indicates the amount of ingested fission product activity to produce one rad dose to the lower large intestine and Graph 5 shows the relative doses to the gastrointestinal tract and the thyroid. It may be seen that ingestion of a given activity on the fourth and fifth days may result in nearly two and one-half times the dose to the thyroid as to the lower large intestine. For a continuous consumption of fallout material from the first hour to the 30th day the ratio of doses is about 1.7.

3. Bones

It is recognized that the intake and deposition of strontium-89 and 90 are intimately associated with the calcium in the diet. Whereas it has been assumed here that a fixed percentage of the strontium intake is deposited in the bones (reference 5). It is realized that this method involves uncertainties, as would the necessary assumptions to generalize for a wide variety of calcium—strontium ratios and intakes to cover multiple categories. In situations where doses to the bones appear to be the critical criterion (such as later times after detonation than considered here), it would be necessary to make a more precise evaluation.

Unequal distribution of isotopes in the bones has been observed. Thus, the dotted line in Graph 5 is included to suggest a possible larger dose to those regions.

Considerable data have been collected on radiation produced bone cancers. One summarizing statement that places this in proper perspective with the other factors discussed above is "...Visible changes in the skeleton have been reported only after hundreds of rep were accumulated and tumors only after 1,500 or more."[illegible] When one examines Graph 5 for relative doses, and reviews the data on doses versus effects to the gastrointestinal tract and possibly children's thyroids (Table IV), it would appear that exposure to the bones is not the critical factor for ingestion of fallout material under emergency conditions, for the first few weeks after detonation.

TABLE IV

Some Possible Biological Effects from Radiation Doses to Specific Organs*

Dose (Rads)	Gastrointestinal Tract	Thyroid	Bones
10,000		Minor changes in structure	
	Serious damage—survival threatened		Tumor production.
1,000	Tumor Production		
	Immediate effects such as nausea	Potential carcinogenic dose to few percent of children	Minor changes in structure
100			

* Lesser short term effects would be expected from the same doses distributed in time.

4. Summary of Biological Effects

Table IV summarizes some possible biological effects from radiation exposures. Due to inherent uncertainties in such analyses together with expected wide biological variances among individuals, Table IV is intended only to suggest a generalized picture of doses versus effects.

The physical calculations of radiation doses made above were for adults. For equal intakes of radioactivity, children probably would receive higher exposures due to the smaller organ masses, and in the case of bones a greater deposition would be expected. Also, there is the possibility of tumor production in the thyroids of some children at relatively low radiation exposures. It would appear wise therefore to establish lower limits of intake of radioactivity for children.

C. Permissible Intake

The preceding discussion attempts to give estimates of radiation doses resulting from intake of fallout material, together with some possible biological effects. How much intake is actually permitted depends upon many factors including the essentialness of the food and water to sustaining life, and one's philosophy of acceptable biological risks and damage in the face of other possible hazards such as mass evacuation. Table II and Graph 5 give estimates of the amount of contamination in food and water to produce certain radiation doses to the critical organs. Table IV indicates possible biological effects from given doses. Using these references, command decisions may be made as to permitted intake of radioactivity.

Such evaluations as attempted here are necessary and valuable for planning purposes, but once the fallout occurs the emergency of the situation may preclude immediate analysis of the food and water supplies. Further, abstaining from ingestion of food and water because it

TABLE V
Mean Body Burden of Rongelapese

Radioisotopes	Estimated Activity at One Day (μc)
Sr^{89}	1.6–22
Ba^{140}	0.34–2.7
Rare earth group	1.2
I^{131} (in thyroid)	6.4–11.2
Ru^{103}	0.013
Ca^{45}	0.019
Fissile material	0.016 (μgm)

might be contaminated could not be continued indefinitely. Therefore, the following three common sense rules are suggested:

1. Reduce the use of contaminated food and water to bare minimum until adequate monitoring can be done; use first any stored clear water and canned or covered foods; wash and scrub any contaminated foods and;

2. If the effects of lack of food and water become acute, then use whatever is available but in as limited quantities as possible. Whenever possible select what seems to be the least likely contaminated water and/or foodstuffs; and

3. Since it is especially desirable to restrict the intake of radioactivity in children, give them first preference for food and water having the lowest degree of contamination.

In an area of heavy fallout one matter to consider is the relative hazards from the external gamma exposure versus internal doses from ingestion of the material. (Inhalation is thought to contribute only relative minor doses under the conditions discussed here). The best evidence on this point is the fallout that occurred on the Rongelapese in March 1954. Those in the highest exposure group received 175 r whole-body external gamma exposure yet their body burdens of internal emitters were relatively low (Table V).[30] These and other data suggest that:

If the degree of contamination of an area is such that the external gamma exposure would permit normal and continuous occupancy after a fallout, the internal hazard would not deny it.

This is based on such reasonable assumptions of (a) about 50% reduction of gamma exposure from out-of-doors doses afforded by living a part of each day in normal family dwellings, (b) washing and/or scrubbing contaminated foods, and (c) excluding areas where relatively little fallout occurred, but into which may be transported highly contaminated food and/or water. After longer periods of time during which the gamma dose rates in an originally highly contaminated area have decreased to acceptable levels, it probably would be necessary to evaluate the residual contamination for the bone seeking radioisotopes, especially strontium-90.

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Representative HOLIFIELD. Dr. Stanton H. Cohn will present testimony on the evaluation of the hazards from inhaled radioactive fallout. Dr. Cohn is presently with the Medical Physics Division, Medical Research Center, Brookhaven National Laboratory. He is a member of the Subcommittee on Inhalation Hazards of the Pathological Effects of the Atomic Energy Radiation Committee of the National Academy of Sciences. He was a member of the U.S. Naval Medical Team which provided emergency medical treatment to the Marshallese accidentally exposed to fallout from operations in 1954. He studied the internal radioactive contamination of the exposed Marshallese. He was also a member of the AEC medical team which made the 5-year medical survey of the Marshall Islands in 1959 and studied the internal radioactive contamination by measuring body burdens of various fission products of 250 Marshallese using a whole body gamma scintillation counter. He participated in the direction of the study of the residual contamination of plants and animals of the Marshall Islands in two surveys in 1955 and 1956.

Dr. Cohn, we are happy to have you before us today and you may now proceed.

TESTIMONY OF DR. STANTON COHN,[1] BROOKHAVEN NATIONAL LABORATORY

Dr. COHN. An individual exposed to an atmosphere contaminated with airborne radioactive particles will be subjected to both external and internal radiation. This contaminated atmosphere, which would most likely be an area of local fallout produced by a nuclear detonation, would subject the individual to penetrating gamma and superficial beta radiation from the exterior. Particles which become internalized as a result of inhalation and/or ingestion would subject the internal tisues and organs primarily to beta radiation, and to a lesser extent, to gamma radiation. Unconsumed fissile material may, in addition, supply internal alpha radiation.

It is difficult to determine the exact degree to which radiation from external and internal sources contribute to the total radiation an individual receives. It is even more difficult, and in fact, rather arbitrary (as will be shown later) to separate the contributions deriv-

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II. Education: University of California, Berkeley, Calif., 1952, Ph. D., physiology-radiobiology (Dr. Hardin Jones and Dr. D. H. Copp). University of Chicago, Chicago, Ill., 1949, S.M., physiology (Dr. Franklin McLean); 1946, S.B., Biochemistry.

III. Additional qualifications: Member of the Subcommittee on Inhalation Hazards of the Pathological Effects of Atomic Radiation Committee, National Academy of Sciences, 1956 to present. Member of the U.S. Navy medical team which provided emergency medical treatment for the Marshall Islanders accidentally exposed to fallout from Operation Castle, March 1954. Studied the internal radioactive contamination of the exposed Marshallese. Also member of the AEC medical team which made the 5-year medical survey of the Marshall Islands in 1959. Studied the internal radioactive contamination by measuring body burdens of 250 Marshallese using a whole body gamma scintillation counter. Participated in the direction of the study of the residual contamination of plants and animals of the Marshall Islands in two field surveys, 1955 and 1956. Member of the Advisory Committee on Civil Defense, 1958.

IV. Scientific Societies, memberships: Radiation Research Society, American Physiological Society.

ing from material which is inhaled, as compared to material which is ingested. However, it appears from all the laboratory studies and the field experiences that following an acute exposure to fallout, the radiation dose to an individual from internal sources as compared to that from external sources will be small. The one possible exception is the dose to the thyroid from I^{131} and the shorter lived iodine isotopes. This means practically that in determining the short-term effects of an acute radiation exposure, the external does is critical.

The chronic, or long-term effects, of an acute exposure may be quite different. When an individual is removed from the contaminated environment, the external dose is terminated. But the radioactive particles which become fixed in the body, adjacent to radiosensitive tissue, continue to irradiate it until they are finally removed by biological turnover, or rendered harmless by radioactive decay. Thus it is apparent that even a small dose rate, when integrated over a sufficiently long term, that is to say, years, produces a significant dose. Thus, we see that the problem of radiation from internal sources is essentially a problem of long-term radiation effects.

I should like to present to you now a more detailed picture of the inhalation aspect of fallout exposure, together with the data which lead to the picture I have just very briefly presented.

I plan to stress the mechanisms and problems associated with the inhalation of radioactive particles and the ensuing effects upon the respiratory system. The more general aspects of the inhalation of radioactive material—that is, the hazard to other organs of the body from material which is translocated from the lungs, will be considered briefly following the discussion of the more specialized topic of inhalation hazards.

The topic which I am covering today has been under surveillance by the Subcommittee on Inhalation Hazards of the Pathological Effects of Atomic Radiation Committee of the National Academy of Science for the past 3 years. While the opinions which will be expressed here are solely those of the author, they do, I feel, reflect to a considerable degree the consensus of opinion of this committee on which I have been privileged to serve.

The fallout with which we are here concerned is local fallout, that is, fallout from surface or subsurface bursts on land or water which returns to the earth's surface within minutes or hours, or at the most, a few days. We are not here concerned with stratospheric fallout, or worldwide fallout, since the dilution of this fallout is such that a hazard from inhalation of such material does not exist.

Determination of the radiotoxicity of inhaled particles can be separated into two aspects: The nature of the aerosol itself, and the reaction of the biological organism to the particular aerosol. In the production of fallout, the radioactive particles generally become attached to a carrier material. The characterization of the aerosol, which determines the biological response, includes, therefore, not only determination of the physical and chemical form of the fission products themselves, but also that of the carrier.

The properties and distribution of radioactive particles from nuclear detonation, as discussed earlier in these hearings, are determined by the type and size of the nuclear detonation. Particles in local fallout vary in size from less than a micron to several millimeters, and

may contain fission products, unconsumed fissionable material and neutron-activated material from the environment. Most of the fission products are formed as oxides which have low solubility, while the carrier material varies widely in solubility.

The reaction of the organism to the radioactive aerosol can be considered in terms of the uptake and distribution of the particles in the body and their retention and eventual clearance. The reaction of the organism is not a simple fixed process, but varies considerably with the physiological state of that organism.

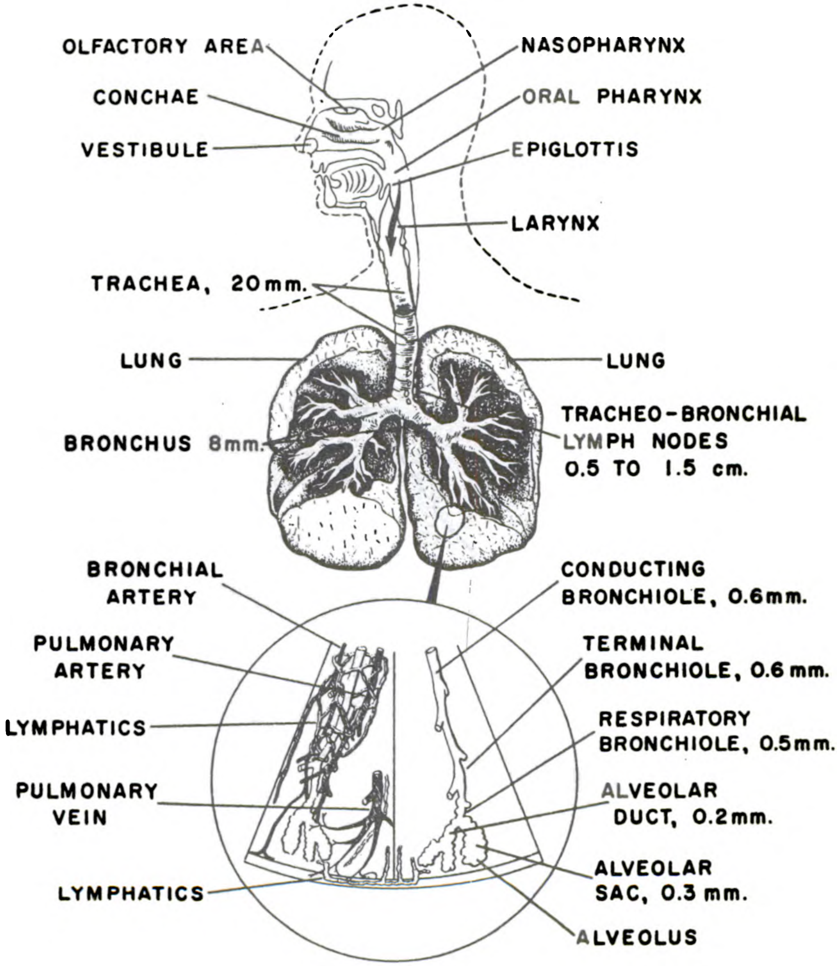
To constitute an internal radiation hazard, the radioactive material does not have to gain access to the circulating blood. Material which is deposited in the respiratory system or in the G.I. tract is still considered an internal radiation hazard.

Once radioactive material gains entry into the circulatory system, the isotopes follow the same metabolic processes in the body as the naturally occurring inactive isotopes of the same element or a chemically similar element. Isotopes which are fixed by the tissues in the body, particularly those which are bound in skeletal tissue, continue to irradiate the body until they are removed by biological turnover or become harmless by the process of radioactive decay.

I would like to make a few observations concerning the anatomy and physiology of the respiratory system in order to provide a background for the discussion of the transport of radioactive particles from the nasal passages to the circulatory system.

As shown in figure 1, air passes from the atmosphere through the respiratory system to the alveoli, where the actual exchange of gases takes place with the circulating blood. The nasal passages, trachea and bronchii, down to the terminal bronchioles, are lined by a membrane which is covered with ciliated cells, and which secretes mucous. For the purpose of this discussion, we will consider the respiratory tract to consist of two regions, the upper respiratory tract (which is the ciliated area) and the lung, which is the region below.

THE RESPIRATORY TRACT

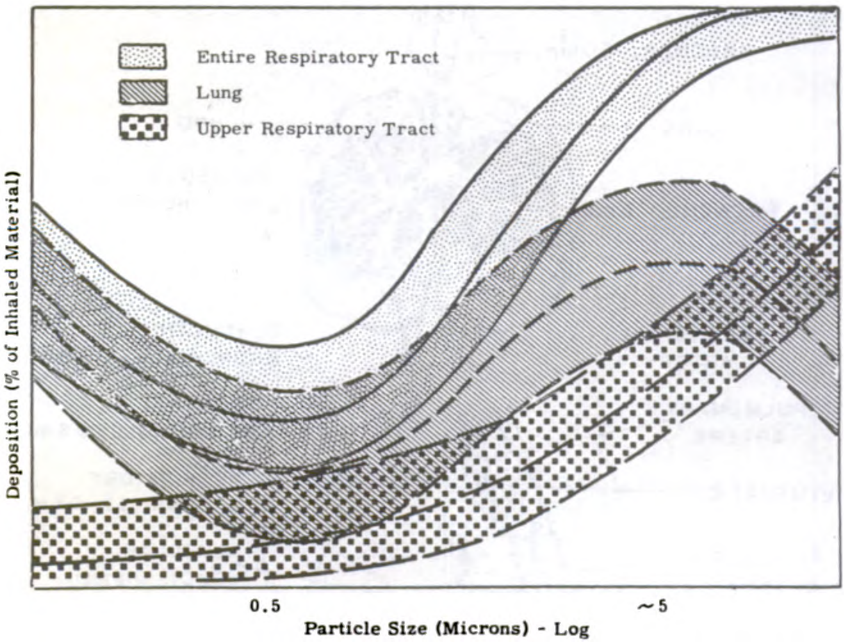


LUNG LOBULE

When inhaled fallout material enters the respiratory tract, a fraction of the material is retained. Some of this material is subsequently removed, but a portion may remain for an appreciable period. Probably the most important property of fallout which influences the fate of the particles in the respiratory system is the size of the particle.

Both experimental and theoretical data on the deposition of particles with respect to particle size are summarized in figure 2. For decreasing particle size, as would be expected, deposition occurs deepest in the lung. With the increasing particle sizes, deposition occurs in the higher areas of the respiratory tract. A minimum in lung deposition occurs at 0.5 micron, and a maximum at 5 microns. Particles larger than 5 microns are retained by the upper respiratory tract and do not reach the lung. The nasal air passage acts as a trap or filter for these larger particles.

FIGURE 2



Deposition in Respiratory Tract

The rates of clearance of material from the respiratory tract are also important because they influence the tissue exposure time and thus determine the degree of radiation hazard to the lungs. The clearance of material from the lungs has not as yet been clearly delineated. However, it is thought that three mechanisms play a role in the removal of particulate material. These are ciliary action, transfer of soluble material across the alveolar membrane and phagocytosis. The action of ciliated epithelium in combination with mucous secretion results in a rapid "escalatorlike" upward movement

of material deposited in the respiratory tract above the terminal bronchioles. Materials in the ciliated upper portion of the respiratory tract are removed to the G.I. tract within hours, or at most, a few days. Ciliary action is a continuous process and accounts for the removal of the largest fraction of particles from the respiratory tract.

Relatively soluble material is transferred across the alveolar membrane into the bloodstream, and thus enters the circulation in minutes, or at the most, a few hours. The material appears equally rapidly in the organ of ultimate deposition. The radiation dose to the lungs from such soluble material is much less than that received by the organ of ultimate deposition, which is usually the skeleton, because of the brief transit time in the lungs.

To a limited extent, the so-called insoluble materials are also absorbed through the lung and the G.I. tract.

The third method for removal of particulate material from the lung is phagocytosis, that is, engulfment of a particle by a phagocytic cell. A phagocytized particle may be moved into an alveolus and transported upward, or the phagocyte may enter the lymphatic circulation and be transported to the lymph nodes.

To provide a basis for estimating the accumulation of the many types of radioactive material in the lung in situations where actual data are not available, the International Committee on Radiation Protection (ICRP) has derived a model to describe general respiratory characteristics of deposition and clearance, as shown in figure 3. The total deposition of (50 percent plus 25 percent) or 75 percent for readily soluble compounds is conservative for most size ranges. The figure is 25 percent for deposition in the lung is based on animal studies, and may vary widely. For insoluble material, in addition to the 50 percent which is removed from the upper respiratory tract and swallowed, an additional 12.5 percent is removed from the deeper portions of the lung by ciliary action and swallowed.

The overall elimination rate of fission products from the lung can be described by a series of exponential functions (rate proportional to level), and over a longer period of time by a power function (rate of removal decreases geometrically with time). These rate values are needed to provide meaningful calculations of radiation dose.

FIGURE 3

Distribution of particulates in respiratory tract

Distribution	Readily soluble compounds	Other compounds
	Percent	*Percent*
Exhaled	25	25
Deposited in upper respiratory passages and subsequently swallowed	50	50
Deposited in the lungs (lower respiratory passages)	[1] 25	[2] 25

[1] This is taken up into the body.
[2] Of this, half is eliminated from the lungs and swallowed in the first 24 hours, making a total of 62.5 percent swallowed. The remaining 12.5 percent is retained in the lungs with a half-life of 120 days, it being assumed that this portion is taken up into body fluids.

It can be seen from the preceding discussion that the body has certain natural defenses against inhalation of fallout. First, the nasal passages and lungs act as a filter against large particles. Secondly, the alveolar and G.I. tract membranes filter on the basis of solubility.

Finally, much of the material which gains entry into the lungs is transferred to the intestinal tract where it is lost through normal elimination. In addition to these physiological protective factors, many of the fallout fission products produced have very short radioactive half-lives.

Very few data exist correlating a given amount of an internal emitter and a specific pathological response. Information on pathological injury to the lungs of human beings is derived largely from data on the effect of external radiation in the treatment of cancer of the breast and intrathoracic neoplasms. Two main types of lesions are formed, radiation pneumonitis and radiation fibrosis, representing different types of damage to the alveolar cells and wall. While individual variation in response to radiation are very large, there is a definite correlattion of the frequency of the above lesions with external dose.

Clinical experience on the effects of radioactive material deposited in the lungs is derived primarily from miners who were exposed for long periods to radium dusts and radon gas in mines. The best known cases of lung cancer caused by radium are those that occurred in the miners of Joachimsthal and Schneeberg in Czechoslovakia. While an increase in the occurrence of lung caner of the order of 50 percent was observed as compared with the general population, the etiology of the cancer is linked only circumstantially to the radium.

Other date on the pathological effects of radiation to lung are meager, and are based in part on experience with individuals exposed accidentally to radiation or radioactive materials or to high doses of therapeutic radiation. In accidental cases, the radiation dose received is most often unobtainable. Data on the late effects resulting from radiation therapy are very scarce, as frequently the followup on such effects is not made, and further, the study requires difficult statiscal analysis.

The best source of data is the study of radiation effects on laboratory animals. From animal experimentation it is concluded that lung as a tissue has only moderate radiosensitivity. Damage is observed in lung tissue only after a large acute dose or repeated smaller doses of external radiation.

There is no question that radiation from internal sources can produce lung cancer, but it is not as yet possible to equate the changes produced with given levels of radiation dose. The best estimate of the external dose required to produce pulmonary fibrosis and pneumonitis lies in the range of 800 to 2000 rads, with a mean dose of about 1,000 rads. The induction of pulmonary cancer from radioactive material in experimental animals requires a dose of about the same order. The smallest dose to the lung which produced malignant tumors in mice was reported as 115 rad, following administration of 0.003 μc $Pu^{239}O_2$, and 300 rads after administration of 0.15 μc $Ru^{106}O_2$. However, other studies with mice have indicated that 2,000 rad was the threshold dose for lung tumor formation. Actually, almost all of these studies utilize intra-tracheal administration of the material for experimental ease. It is difficult to compare such an exposure to one deriving from true inhalation.

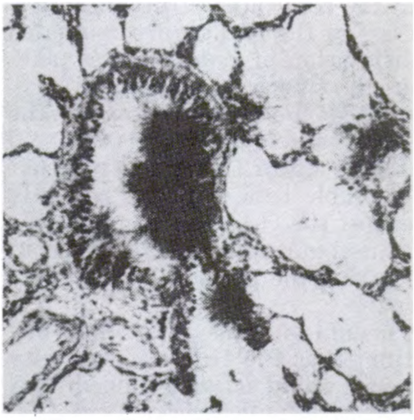
In a consideration of inhalation hazards, the effects of inhaled fission products on organs other than the respiratory tract must also be taken into consideration. Regardless of the nature of the inhaled material, a significant degree of translocation of radionuclides takes place from the lung to the other organs and tissues.

On the basis of the figures in the ICRP model, 50 percent of the soluble material and 62.5 percent of the insoluble material is removed by ciliary action to the G.I. tract. The result of this activity is that following inhalation of soluble or insoluble beta emitters, not only the respiratory tract, but also portions of the G.I. tract may become the "critical organ," that is, the organ containing the highest concentration of radioisotope. In fact, during the period of inhalation, the G.I. tract usually is the critical organ.

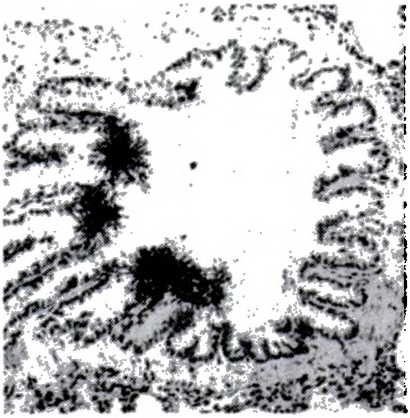
Actually, we have found in experiments on mice exposed to dry particle aerosols labeled with strontium that the G.I. tract activity was as high as 100 times the respiratory system activity immediately after exposure. These data emphasize the importance of the G.I. tract as a portal of entry following inhalation. It is apparent, therefore, that evaluation of the internal hazard associated with an inhalation exposure to radioactive fallout must take into account those parameters which influence the transport of particles across the G.I. membranes as well as the more commonly considered factors which determine transport across the alveolar tissue.

In order to evaluate the effect of inhaled radioactive fallout and to compare the internal hazard to the lung to that produced by external radiation, it is necessary to calculate the radiation dose to the lung from the internally deposited material. If the actual distribution of the radioactive material were known, it would be theoretically possible to calculate the dose. At present there is no practical way to measure accurately or directly the dose to the lung due to the deposition of radioactive material therein. Estimates are usually made of the dose, based on the premise that the material is distributed uniformly in the lung tissue. This, of course, does not correspond to the actual situation. Further, recent work indicates that particles removed from the lungs may be collected in tracheobronchial lymph nodes, as shown in figure 4, and remain there for long periods of time. Concentrations in the lymph nodes may greatly exceed those in the lung. The importance of these concentrations in the evaluation of the inhalation hazard is one of the points which requires further investigation.

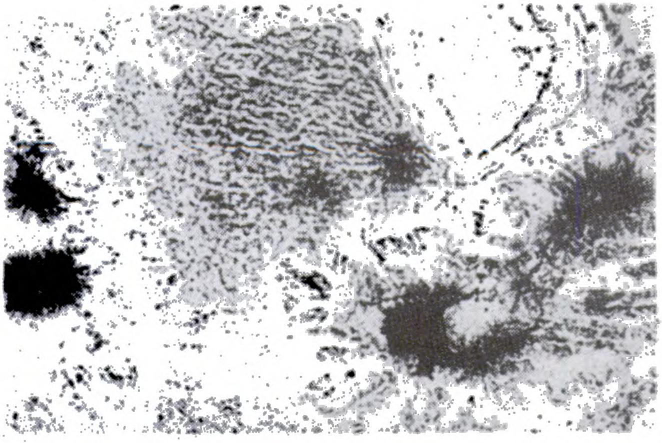
FIGURE 4



Po^{210} Aggregates
in Small Bronchiole
2 Hours after Inhalation



Po^{210} Particles at Points of Entry
from Smaller to Larger Bronchioles
12 Hours after Inhalation



Po^{210} Particles in Large Bronchioles and Adjacent Lymphoid Tissue
24 Hours after Inhalation

Accumulation of Radioactive Particles in Rat Lung
at Various Times after Inhalation

While it is difficult to calculate a radiation dose from individual fission products, the problem of calculating the dose to the lungs following an exposure to mixed fission products is vastly more difficult, as it involves consideration of the composite decay characteristics of the fission products as well as their complex energy spectrum. In addition, there is again the basic problem of how to deal with the inhomogeneous distribution of radioactive particles in the lung. This nonuniform distribution of inhaled particles in the lung is shown in figure 5. The problem of evaluating the efficiency of "hot-spot" dis-

tribution versus uniform distribution in the production of injury to the lungs is an unresolved problem at present. It is the same problem met with in calculating Sr^{90} doses in bone. It should be noted that all the doses that I have been here discussing are based on the uniform distribution of the internal emitter and its exponential loss from the lung. Actually, the local dose surrounding the hot particles can be manyfold greater than the average tissue dose.

Autoradiogram Showing Alpha Tracks in Lung and Lymph Node of a Mouse 100 Days after Intratracheal Administration of 2.5 μc $Pu^{239}O_2$ (18X) (Ref. 52)

The calculated beta radiation dose to the lung itself, resulting from breathing in an atmosphere of airborne fallout, is small when compared with the external gamma radiation from the fallout cloud. Laboratory experiments also bear out this conclusion that the external dose is the limiting hazard in an acute exposure to local fallout.

The data on which the various conclusions regarding the uptake, distribution, and retention of fallout material are based, come from three main sources. First are the animals which have been exposed to fallout in various field tests. Secondly, we have a very limited experience with human beings who were accidentally exposed to fallout during the Pacific tests that were held in the spring of 1954. Finally, there are the animals which have been exposed, under controlled conditions, to artificial fallout in laboratory experiments.

In field studies, conducted at the Nevada Test Site, involving the acute exposure of animals to radioactive fallout, the retention of particulate matter in the respiratory system of the exposed animals was found to be quite small in the presence of an appreciable external radiation flux.

In the Pacific nuclear weapon test of March 1, 1954, a number of human beings and animals were accidentally exposed to airborne fallout. The amounts of the radionuclides taken up and retained by the animals were considerably larger than those taken up by the experimental animals used in the continental tests, partly because the Pacific test involved a different type of detonation, and partly because the carrier material of the fallout was considerably more soluble than that encountered in the Nevada tests.

The Marshallese people were subjected to an acute inhalation and an ingestion exposure for 48 hours, prior to evacuation. Their body burdens of internal emitters were estimated from data obtained on the animals simultaneously exposed. These data are probably indicative of the qualitative nature of the inhalation exposure, even though they reflect the greater ingestion of the contaminant that occurred during the prolonged stay of the animals on the island. Again, it is difficult to separate the inhalation and ingestion components in such an exposure to fallout.

Although a large number of fission products were present in the environment after the Pacific tests, only a half-dozen or so nuclides need be considered. The most important internal emitters are Sr^{89}, Ba^{140}, I^{131} and the shorter-lived iodine isotopes, as well as some of the rare earth elements, as shown in figure 6. These isotopes are characterized chiefly by their solubility as well as their abundance in the fission yield.

FIGURE 6

Internal radioactive contamination of Marshallese pigs exposed to fallout from the Mar. 1, 1954, nuclear detonation [1]

	Beta activity d/m/total sample × 10^{-3}			
	Gross activity	Sr^{89}	Ba^{140}	Rare earths
Skeleton	8,745	5,380	595	850
(Total, percent)	(100)	(62)	(6.8)	(9.7)
Lungs (alveolar)	1.3	0.24	0.22	0.57
Stomach	1.6	0.26	0.62	0.80
Small intestine	2.5	0.73	0.69	0.69
Large intestine	14	5.0	2.8	4.0
Liver	29	0.47	0.27	5.9
Kidney	3.2	0.18	0.30	0.61
Remaining carcass	455			
Thyroid dose	100–150 rep—(estimated from early analysis of urine).			
Total external gamma dose	330 r.			
Internal beta activity	4 μc.			

[1] These values are the average of 2 young adult pigs which were analyzed 3 months after detonation.

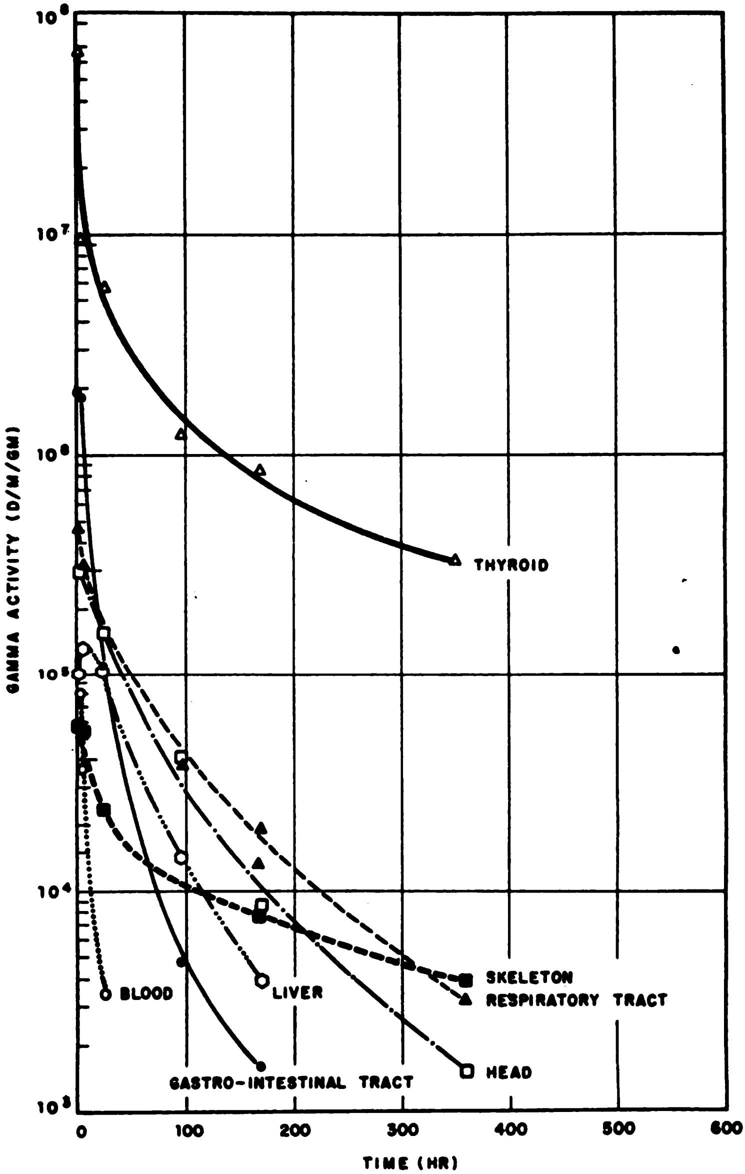
It can be seen that I^{131} and the shorter-lived I^{132}, I^{133}, and I^{135} contribute the highest individual tissue dose (100–150 rep to the thyroid). Although this is a large dose, studies with sheep indicate that doses of 16,000 r. are required to produce minimal changes in cell structure, and 50,000 r. are required to produce definite acute cell damage and hypothyroidism. Of the remaining fission products, Sr^{89} contributed the major portion of the beta dose to the skeleton. Thus the contribution of the total internal contamination in the Marshallese was small as compared to the 175 r. external gamma dose which they received.

In laboratory experiments designed to reproduce exposure to early fallout from various types of nuclear detonation, products from 2-day-old neutron bombarded uranium associated with various types of carriers were employed as fallout simulants.

In these inhalation experiments mice received an acute exposure from many of the short-lived radioisotopes not previously studied. The distribution, retention, and clearance of the fission products in these animals confirm the fact that the uptake and metabolism of the inhaled radioactive particles depend largely on the physical and chemical characteristics of the carrier material. The internally deposited radioactivity in the lungs, as well as in the skeleton and soft tissues (as shown in figure 7) decayed rapidly because the activity of the aerosol was contributed chiefly by short-lived radioisotopes and the biological loss of material from the lungs and soft tissues was very rapid.

While, as mentioned previously, the calculation of the internal radiation dose from fallout with any degree of precision is difficult, a rough approximation based on the experimental data here is feasible. To evaluate dose to individual tissues following this acute inhalation exposure, the activity per gm tissue as a function of time was determined. The greatest activity per gm tissue was observed in the thyroid at 1 hour following exposure. The total dose received by each organ for comparable energies is proportional to the area under its curve.

FIGURE 7



UPTAKE & RETENTION BY MICE OF A SIMULANT OF FALLOUT PRODUCED BY A LAND BASED NUCLEAR DETONATION.

The thyroid in this experimental situation, as in the Marshallese people, received the highest dose to any tissue from the internally deposited fission products. The G.I. tract received the next highest dose, and the dose to the skeleton, while very low in the 15-day period studied is greater than to other tissues over a longer period of time, since skeletal activity falls off more slowly than that in other tissues. The internal radiation dose to individual tissues was, with the possible exception of the dose to the thyroid, lower than the concomitant external dose received by the animals.

Representative HOLIFIELD. Thank you very much, sir.

May I ask if there are any simple types of breathing masks which people could use in time of emergency, which would eliminate this particulate matter in the atmosphere. If so, how extensive and how complicated would these masks have to be?

Dr. COHN. The answer to your question is yes. I think a relatively simple mask which would filter out particles from 1 to 5 microns—this is not very difficult—would prevent the inhalation of material and thus negate any possibility of an inhalation hazard.

Representative HOLIFIELD. Could you take an ordinary handkerchief, for instance, and arrange it over the mouth and nose to the point where it would filter out a great deal of the airborne particles?

Dr. COHN. Yes, I think this would help. I don't know whether it would filter all the particles, certainly not all the small ones. But it would be very beneficial.

Representative HOLIFIELD. By what proportion would it reduce the full amount?

Dr. COHN. I can't say, since it would depend on the nature of the fallout. Of course, it would filter out mostly the large particles.

Representative HOLIFIELD. They would be the most dangerous, of course.

Dr. COHN. No. Particles over ten microns don't get into the respiratory tract at all and the large particles are deposited in the upper respiratory tract. I think you would be most concerned with particles which are small enough to penetrate deeply into the lower respiratory tract where they can be fixed for long periods of time.

Representative HOLIFIELD. Would most of these be strained out by a linen handkerchief or a fine cotton handkerchief?

Dr. COHN. I have never actually tried this. I think it would certainly be beneficial.

Representative HOLIFIELD. There are simple masks such as the surgical mask, used by doctors in surgery for ordinary respiratory protection, that would probably be more efficient.

Dr. COHN. Yes. I might add that the inhalation hazard is quite a problem in mines where you have an atmosphere of airborne activity from radon and thoron. It has been found that by relatively simple ventilation procedures that it has been possible to lower the airborne activity by quite sizable amounts.

Representative HOLIFIELD. If we did have some shelters, pulling the air in through a simple hand manipulated suction fan through a series of fine cloths would, in effect, screen most of this material out; would it not?

Dr. COHN. Yes.

Representative HOLIFIELD. Are there any further questions?

Representative HOSMER. I think Dr. Cohn ought to be congratulated on his clear, lucid, and understandable statement. The only thing I would like to ask, Doctor, is in connection with the Marshall Islands, this morning we heard that there were 175 rad total dose. I imagine the fraction of that which was attributed to inhalation and ingestion was quite small. Was it determinable?

Dr. COHN. Yes, it was determinable. I can give you the actual figures on the body burden in microcuries. I think the next speaker is probably going to discuss this.

We are talking about levels of strontium 89 and barium 140 of 1 to 2 microcuries. These we consider to be very low compared with the external dose that these people received.

Representative HOSMER. It is a small portion of the radiation they received.

Dr. COHN. Yes.

Representative HOSMER. I would take it that your examination showed no observable effects.

Dr. COHN. To date there has been no effect that we can detect in these Marshallese—at least over the 5-year period that we have been studying them—that we can attribute to radiation, internal or external.

Representative HOSMER. How about immediate effects with respect to internal, were any of those observable?

Dr. COHN. It would be very difficult to distinguish between the effect resulting from the internal as opposed to the external radiation because the effects are very much the same. I don't think one could estimate what the contribution of internal radiation was to the whole picture. Certainly it was very small, but nevertheless detectable.

Representative HOLIFIELD. Thank you very much.

At this point without objection I shall place in the record statements submitted by Dr. J. N. Stannard [1] and Dr. E. L. Alpen.

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[1] Biographical sketch of J. N. Stannard, University of Rochester School of Medicine and Dentistry.

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ACUTE EFFECTS OF INHALATION OF FALLOUT DEBRIS AND ASSOCIATED HAZARDS

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In the broad picture, hazards from inhalation of radioactive dust or other toxic materials produced in a nuclear attack will always be secondary in importance to blast, thermal burns, and external radiation exposures. Yet they cannot be neglected entirely since under certain circumstances they may add enough additional burden to spell the difference between death and survival. Also very occasionally inhalation exposures might constitute the chief hazard.

These several possibilities will be considered below, first those associated closely with a nuclear bomb burst and the succeeding few hours or days, and second, in the situation of persistent environmental contamination.

I. Inhalation exposures following a nuclear bomb burst

A. Immediate problems (Early phase)

In the first few hours after an attack with nuclear weapons inhalation exposures assume importance only for individuals protected from blast, thermal energy, and/or external radiation from the fireball and/or residual fission products in the immediate fallout. This could only occur in shelters or at considerable distance from the burst. The possibilities can be considered under the following headings:

1. Inert dust inhalation. There is evidence that many deaths occurred in bombing raids during World War II without visible signs of injury or of shock. In some instances, the lungs were found to be quite edematous and to contain a large number of particles derived from plaster dust, brick dust, etc. With the ground burst of nuclear weapons postulated for these hearings colossal quantities of non-radioactive dust can be expected. The particle size range would almost certainly include some small enough to enter the ventilation system of shelters, and the respiratory tract of man.

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Suitable filters on ventilation intakes, simple respirators, or even a wet towel should reduce this hazard considerably in shelters but a considerable dust load could enter the lungs before such remedial measures were taken if not planned for in advance. This type of exposure should be of little importance to individuals at sufficient distance from the burst to be protected by distance alone.

2. Toxic gas inhalation. In our preoccupation with radiation hazards we should not forget the possible presence of acutely hazardous quantities of various toxic gases in the air. It would be expected that the enormous up-drafts produced by the burst itself would remove most of the toxic gases (such as steam, illuminating gas, industrial gases, etc.) initially released by the destruction of structures. However, in the fires and fire storms following a nuclear attack large quantities of carbon monoxide, carbon dioxide, and other products of combustion might be produced for considerable periods after the burst and enter shelters. These could easily present an acute hazard in local situations.

Estimation of their relative importance is not possible within the framework of the present hearings. They would still be secondary in general importance to fire, blast, and external radiation casualties, but might be of critical importance at some key location. It is clear that many casualties occurred in World War II which could be accounted for only on the basis of the inhalation of overwhelming quantities of toxic gases.

Protection against this type of inhalation exposure requires more than a simple filter or wet towel. Various chemical absorbers developed by the Army Chemical Corps and by industrial firms could be employed either at the air intakes for shelters, in the shelter areas, or in gas mask canisters. The "all-purpose" absorbing chemical would be most versatile but it has definite limitations in capacity against any single gas. Also none of these chemicals can protect against an environment where the oxygen content itself has been

depleted and replaced by irrespirable gases. The only really safe procedure is provision of an independent self-contained air supply for the shelter or provision of self-contained breathing equipment for those present. Both of these may be beyond the scope of practical shelter planning, but should be considered for critical installations at least.

3. Radioactive dust inhalation. The radioactivity present in fission products or induced in the material of the bomb and/or debris consists predominantly of the penetrating gamma rays and the less penetrating beta particles. The chief hazard immediately and for a few hours after release lies in the effect of the gamma rays on internal organs and of beta particles on the skin. It is difficult to conceive of a situation where protection against this external radiation hazard during the immediate hours after a nuclear attack would not protect also against danger of acute radiation damage from inhalation of the radioactive dust. The same applies to longer term effects after early exposure since the rate of radioactive decay is rapid and even those amounts entering the lung will soon decay to vanishingly small doses in terms of acute damage. The only anticipated effect would be long term, as described subsequently.

The situation is somewhat modified in considering situations such as those pertinent to rescue workers. The rapid initial decay rate may have reduced the level of gamma irradiation sufficiently to make operations possible within a limited area. Stirring up dust in the rescue operation might conceivably present an important inhalation hazard. However, experimental work done in Britain indicates that here too the external radiation level will be the controlling factor. (These were experiments using activated dust, mainly sodium^{24}, or iodine^{131} adsorbed onto inert dust.) In the hypothetical fallout fields described for these hearings only very limited rescue operations could be carried out in the early periods without protection from external radiation.

B. Later problems (Intermediate phase)

The problem here will be considered primarily as it relates to inhalation of radioactive dust. After the first few hours the problems with inert dust or toxic gases would probably be of only routine interest in the context of these hearings.

Dr. Stanton Cohn's paper has summarized the processes of lung deposition and clearance of dust and the behavior of radioactive particles in the lung. These points will not be repeated here in any detail. Suffice it to say that material must be smaller than 5 microns in size to enter the respiratory tract in any significant quantity and once deposited it is cleared from the lung by several processes with considerable efficiency. Ordinarily, less than a quarter of that entering remains for any significant time. Much of the removed material can be found in the gastrointestinal tract and for that reason intestine (particularly the large intestine) may actually receive a larger radiation dose than the lung at certain times after an inhalation exposure. Also, if the material is readily soluble it may be quickly transported from the lung to other tissues such as bone, kidney or thyroid. Thus an inhalation exposure which resulted in deposition of radioactive materials in the lung could potentially irradiate several tissues. Sometimes the lung dose is small in comparison to other tissues, sometimes, e.g., when particles remain in the lung for long periods or accumulate in the pulmonary lymph nodes in quantity, the lung and its accessory structures receive the principal dose.

Assuming some protection from the external radiation dose associated with the initial and residual nuclear radiations, or that the dose received was not fatal, what effects might be expected from inhaled radioactive dust? They will assuredly be largely of relatively long term significance. Pulmonary fibrosis or pneumonitis are commonly associated with large radiation doses to the lung (several hundreds to a few thousand rads). Bronchogenic carcinoma can be induced

by radioactive materials but the radiation doses needed are not known with any certainty. They are probably not small. $Iodine^{131}$ and associated short-lived isotopes of iodine might give appreciable doses to the thyroid. But the thyroid has turned out to be a relatively radioresistent organ in the adult and this dose would probably not be serious as an acute dose except in young children. $Strontium^{89}$ would deposit in bone and present a finite possibility of inducing osteogenic sarcoma or bone marrow damage. The rare earths might deliver a significant dose to liver.

Estimation of the dosages delivered after mixed fission product inhalation is not possible without broad assumptions and a wide range of probable values. However, we have had experience from field tests, laboratory experiments, and the accidental exposures of animals and humans in the Marshall Islands. All of these data show that the dose to the thyroid from iodine isotopes will be the largest single internal dose. G.I. tract will come second in most instances (in terms of total dose). Respiratory tract and skeleton will come third. In all cases the total internal doses will be small compared to the external radiation dose. But the continuing presence of radioactive materials in the body over long periods is quite different from a single dose of external gamma radiation. Thus the relatively small doses delivered after inhalation may not be completely innocuous despite the large difference in doses.

Dr. K. Z. Morgan prepared for a Symposium on the Shorter Term Biological Hazards of a Fallout Field (AEC-DOD, December 1956) tables for single exposures to radionuclides sufficient to deliver various doses compatible with occupational exposures. I have taken the liberty of scaling some of these to amounts which

would deliver doses of 25 or 100 rem in one year.* The amounts of various nuclides required to deliver these doses is summarized in Table I. The numbers are probably conservative for emergency use and may not have much real meaning. However, they can be considered in the context of the postulates for these hearings.

You will note that the amounts required to produce the given doses in lung are generally lower than those required for other critical organs. However, we have many indications that the lung is only moderately radiosensitive and these differences therefore may be less significant than the similarities in the several values. For the purpose at hand, in fact it is the similarities of many values in Table I which are to be noted.

Some elements such as C^{14}, Na^{24} must be present in sufficiently large quantities to almost deserve elimination from the table. They are given for purposes of comparison of fission products and induced activity. One of the larger differences between lung and another critical organ, and in the opposite direction from the usual, is seen with I^{131}. However, a dose to thyroid as high as 2000 rads may be permissible in an acute incident. In this case, the permissible air content of iodine isotopes would be scaled upward when thyroid is critical organ.

Of the fission product elements listed probably I^{131}, Sr^{89}, Ba^{140} + La^{140}, Ca^{137} + Be^{137m} and Ce^{144} + Pr^{144} may be of the most interest.

The permissible amounts of alpha emitters are considerably lower than those of the fission products largely because of the introduction of a factor for relative biological effectiveness in calculating the rem dose. The amounts of alpha emitters present would be small in the situation envisaged for

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* You will remember that 25 rem is often suggested as the tolerable single dose and even 100 rem may be tolerable under conditions of a national emergency. Since the radiation from radioactive materials cannot be "turned off", the period for accumulating the dose is lengthened considerably for this calculation over the few hours to days involved in external dose considerations. In general, the major portion of the dose will have been expended by one year; thus the choice of this period.

TABLE I

AMOUNTS OF VARIOUS ISOTOPES CALCULATED TO PRODUCE TOLERABLE EMERGENCY RADIATION DOSES

(AMOUNT INHALED IN ONE DAY TO DETERMINE INDICATED DOSE TO CRITICAL ORGAN)

Isotope	Critical Organ	Amount in $\mu c/cm^3$ for 25 rem in 1 year	Amount in $\mu c/cm^3$ for 100 rem in 1 year
	Fission Products and Induced Activity		
C^{14}	G.I. Tract	6×10^{-3}	2.6×10^{-2}
	Lungs	3×10^{-5}	1.3×10^{-4}
Na^{24}	Total Body	10^{-3}	3.8×10^{-3}
	Lungs	8×10^{-5}	3.2×10^{-4}
Zn^{65}	Bone	1.4×10^{-3}	5.7×10^{-3}
	Lungs	4.8×10^{-6}	1.9×10^{-5}
Rb^{86}	Muscle	3×10^{-4}	1.3×10^{-3}
	Lungs	10^{-5}	4.5×10^{-5}
Sr^{89}	Bone	1.6×10^{-5}	6.4×10^{-5}
	Lungs	6×10^{-6}	2.6×10^{-4}
$Sr^{90} + Y^{90}$	Bone	1.6×10^{-6}	6.4×10^{-5}
	Lungs	1.3×10^{-6}	5.1×10^{-6}
Y^{91}	Bone	3×10^{-5}	1.3×10^{-4}
	Lungs	6×10^{-6}	2.6×10^{-5}
$Ru^{106} + Rh^{106}$	Kidneys	1.6×10^{-5}	6.4×10^{-5}
	Lungs	10^{-6}	4.5×10^{-6}
$Pd^{103} + Rh^{103}$	Kidneys	4.8×10^{-4}	1.9×10^{-3}
	Lungs	1.3×10^{-4}	5.1×10^{-4}
I^{131}	Thyroid	1.3×10^{-6}	5.1×10^{-6}
	Lungs	4.8×10^{-5}	1.9×10^{-3}
$Cs^{137} + Ba^{137m}$	Muscle	1.4×10^{-4}	5.7×10^{-4}
	Lungs	1.6×10^{-6}	6.4×10^{-6}
$Ba^{140} + La^{140}$	Bone	4.8×10^{-5}	1.9×10^{-4}
	Lungs	6.4×10^{-6}	2.6×10^{-5}
Ce^{144}-Pr^{144}	Bone	6.4×10^{-6}	2.5×10^{-5}
	Lungs	1.3×10^{-6}	5.1×10^{-6}
Pr^{143}	Bone	4.8×10^{-4}	1.9×10^{-3}
	Lungs	3×10^{-5}	1.3×10^{-4}

TABLE I (Continued)

AMOUNTS OF VARIOUS ISOTOPES CALCULATED TO PRODUCE TOLERABLE EMERGENCY RADIATION DOSES

(AMOUNT INHALED IN ONE DAY TO DETERMINE INDICATED DOSE TO CRITICAL ORGAN)

Isotope	Critical Organ	25 rem in 1 year	100 rem in 1 year
	Alpha Emitters		
Po^{210}	Spleen	3×10^{-7}	1.3×10^{-6}
	Lungs	8×10^{-8}	3.2×10^{-7}
U^{235}	Bone or Lungs	3×10^{-7}	1.3×10^{-6}
U-Natural	Kidney	1.6×10^{-8}	6.4×10^{-8}
	Bone or Lungs	1.4×10^{-7}	5.7×10^{-7}
Pu^{239}	Lung	1.4×10^{-8}	5.7×10^{-8}
	Bone	4.8×10^{-8}	1.9×10^{-7}

these hearings. However, some have very long half-lives and thus alpha emitters will need to be considered as chronic exposure hazards, or in the event of having more than the expected amounts present.

It is interesting to note a correlation between these figures and those presented by Marley and Fry (First Geneva Atoms-for-Peace Conference, Vol. 13) in considering the acute exposure to fission products from a reactor accident. They postulated that exposure to 10 curie-sec/m^3 of airborne fission products would be equivalent to 5 r total body gamma plus 50 r beta to the body surface, plus the internal doses. The total was considered equivalent to 25 r whole body exposure and an acceptable single exposure. This translates to about 10^{-4} $\mu c/cm^3$ in the terms used in Table I. Since many isotopes would be present simultaneously rather than singly as in Table I, we might consider that the agreement between the postulats of Marley and Fry and the figures in Table I is usable. Thus it could be postulated that the inhalation (and accompanying ingestion) hazards would be below the levels used for Table I if the measured external gamma dose were less than 5 r in the exposure period (about 1 day), providing the fission product mixtures were roughly comparable to one existing 24 hours after release. While extremely rough, this figure might be placed on the grids of the fallout conditions used for these hearings. If done, it appears that certain very peripheral areas might be entered without respiratory protection for 30 minutes or so at H + 7 hours (i.e., at the edge of the lowest dose rate area at this time). At D + 2 days the second lowest dose rate area might be so occupied. After 2 weeks the two highest areas might be subject to use for rescue and rehabilitation for short periods without respirators for protection from radioactive dust. In each case, the measured dose would need to be referred to the activity at 24 hours.

Clearly, this is a calculation subject to great uncertainties. It is presented only to attempt some order of magnitude guesses regarding the problem

rather than to state (as conservative practice would dictate) that no information can be given. Obviously, the relation between external gamma dose and $\mu c/cm^3$ will be a complex function of time. As the fission product mixture becomes older the ratio of external to internal dose will decrease. Also, the approximation takes no account of particle size, etc., nor does it allow for preferential absorption of elements on different surfaces or different carrier materials. As the time lengthens the problem will become essentially that of long term contamination, which will be considered briefly below.

II. Inhalation exposures in persistently contaminated environments (Late phase).

I note that Drs. Larsen, Retemeier, and Trum are separately discussing the problems of environmental contamination in some detail. They will have undoubtedly taken up the role of food chains, effects on animals, on food supply, and the possibility of upsetting the balance of nature in an ecological sense. By comparison to these, inhalation hazards are rather limited and specialized. $Strontium^{90}$, for example, would rarely be expected to enter the body in any quantity by inhalation as compared with its entry through food or water. However, long-lived alpha emitters or very insoluble beta-gamma emitters may need to be considered. Also, unlikely as its use may seem, it should be remembered that the situation in the event of radiological warfare will be more comparable to the one described in this section than in the earlier discussion.

The most likely sites for inhalation hazards in persistently contaminated areas would seem to be dry dusty areas where fallout debris could be resuspended in the air by animal or human activities. A few tests at the Nevada Test Site have specifically considered this type of problem, particularly as related to alpha emitters. The results indicate that relatively small fractions of activity on the ground reach the lungs or other organs of experimental animals (sheep, dogs, rats, burros) living as long as 160 days in a contaminated field. Thus

the hazards for inhalation would be those of possible long term rather than acute effects. Acute inhalation hazards might exist if people worked carelessly in clouds of dust in these areas. In very dusty areas respirators should be worn routinely, but it hardly seems necessary to consider any special emergency levels for these situations. Application of the occupational exposure standards will not be a hardship, in practice, and anyone surviving to take part in these activities may be quite ready for a return to peacetime radiation exposure standards.

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ACUTE EFFECTS OF INHALATION OF FALLOUT DEBRIS AND ASSOCIATED HAZARDS

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SUMMARY

In the broad picture, hazards from inhalation of radioactive dust or other toxic materials produced in a nuclear attack will always be secondary in importance to blast, thermal burns, and external radiation exposures. Yet they cannot be neglected entirely since under certain circumstances they may add enough additional burden to spell the difference between death and survival. Also very occasionally inhalation exposures might constitute the chief hazard.

Early phase problems: In the first few hours after an attack with nuclear weapons there may be significant inhalation problems to persons in shelters. Of importance for the immediate period may be the inhalation of large quantities of brick, plaster, and similar dust which could cause acute pulmonary changes and filling of the lungs with dust particles and fluid. There is evidence that something like this occurred in World War II bombing raids.

Large amounts of toxic gases will be released in the attack from destruction of public services, industrial plant structures, etc. Much will be drawn upward with the explosion cloud, but some may remain. Also in the fires and fire storms following an attack large quantities of toxic gases such as carbon dioxide, carbon monoxide, and other products of combustion will be produced. If these entered shelters they would produce acute effects even though the shelter provided protection against blast, burns and external radiation. They are a more critical inhalation hazard than any other in the early period following attack. In fact, even if the fission product cloud entered the shelter it would be the external gamma radiation which would be most serious in these early hours rather than the effects of inhaling radioactive dust.

The dust hazard could be controlled by simple filters, wet towels, or respirators, provided these could withstand the initial effects of blast and heat.

The non-particulate gases would require absorbent chemicals in the filter intakes, air purifiers in the shelter, or self-contained breathing equipment. For a really safe installation an air supply completely independent of outside sources would be preferable.

Intermediate phase: After the early acute toxic gas and dust phase, it might be supposed that inhalation of radioactive dust would be a controlling factor. However, the external gamma radiation or beta dose to the skin would still require greater attention. Only in the event of protection from these and some accidental inhalation of the fission products without exposure to the external dose would the internal dose be larger. However, as the fission products age the external dose decreases rapidly and a point comes where the internal dose would be of greater significance. The types of effect of importance are described briefly.

A rough table is presented in the text to show the amounts of various radionuclides which would be expected to produce given doses over one year after an inhalation exposure of about one day. The doses taken were 25 and 100 rem, compatible with emergency exposure conditions. Taking a rough approximation from reactor hazard calculations, it is pointed out that the smaller dose is roughly equivalent to working in an area of mixed fission products with 5 r external gamma exposure during the working period. It appears that this would allow operations without respirators at the very periphery of the fallout pattern given for the hearings at H + 7 hours, in the second lowest zone at D + 2 days and in the higher dose zones at D + 2 weeks. While a rough approximation and full of assumptions, such figures might be used as a simple guide for the use of respiratory protective equipment.

The most important isotopes in this period are I^{131} and related short-lived iodines, $strontium^{89}$ (not $strontium^{90}$), $barium^{140}$ + $lanthanum^{140}$, and probably some of the rare earth elements. Fortunately thyroid is rather radioresistent in the adult and lung appears to be only moderately sensitive to radiation. Hence the figures are not greatly different in terms of air concentrations for the different

elements and different critical organs, with a few exceptions, e.g., in young children, if consideration is given to relative sensitivity factors.

The late phases: In considering persistent contamination the chance of significant inhalation exposure becomes relatively greater than that of external radiation but never as great relatively as ingestion through food or water supplies. Fortunately by this time the activity levels are enough lower to make the problem one largely of chronic, long-term radiation effects. Danger of acute damage from inhalation of radioactive dust is negligible. All laboratory and field tests corroborate this point of view insofar as weapons fallout is concerned.

In view of the radiation levels in this later period, it is assumed that protection can be placed on the same basis as the levels for occupational use. Thus no separate emergency standards seem indicated for this situation. If the emergency were still acute the contribution of these doses to those already received would not be important. If the emergency were past the return to occupational type standards would probably be welcome and not difficult to implement.

Finally, it should be said that I have attempted to put inhalation hazards in perspective to others in a nuclear attack. The result may seem to minimize the effects of inhaled materials. This is only because of the collossal proportions of the other effects and should not be viewed in the context of peacetime standards. On a peace time basis even the inhalation hazards are of considerable magnitude. But they must be viewed as small in the totality of events and primarily of local importance under certain well defined conditions when the fission products are produced by a nuclear detonation. The situation here should not be confused with that applicable to mine atmospheres, reactor hazard evaluation, and the like.

RADIOLOGICAL HAZARD EVALUATION - A CRITICAL REVIEW OF PRESENT CONCEPTS AND A NEW APPROACH THERETO

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INTRODUCTION

In previous approaches to the problem of evaluating the relationship between radiological exposure and mission accomplishment, under emergency conditions, it has been usual to reach an analytical decision on the basis of acute effects to personnel of penetrating radiation. For example, the following statement is to be found in a recent publication: "Chronic effects will not immediately alter the effectiveness of a commander's forces, whereas acute effects might; therefore, any consideration of war-time radiation tolerances for humans must be based upon acute effects and their consequences upon personnel effectiveness."[1] In the broadest sense this philosophy is undoubtedly true and is not novel to the conduct of warfare. It is, however, equally true that in protection from radiological hazards as well as from all other threats to life associated with modern weapons that the long range effectiveness of a fighting force is also an important consideration. It is the aim of this report to present a system of hazard evaluation which allows a more or less unified concept of hazard associated with a given situation and at the same time give some indication as to the reliability of the input data used in necessary decisions.

PART 1

AN ANALYSIS OF PRESENT RADIOLOGICAL HAZARD EVALUATION

The generally used guidelines for hazard evaluation in radiological situations is a table similar to that presented in OpNav Instruction 3441.1A of 12 July 1955. The prototype (see table 1) is in the Handbook of Atomic Weapons for Medical Officers, NavMed P1330 of June 1951. Table IV of this publication or others derived from it, attempt to establish guidelines for those required to make command decisions in radiological situations. The input information supplied is the fraction of the exposed individuals who might be expected to become sick or succumb to radiological injury as a result of exposure to a given dose. The most pertinent question at issue is whether a realistic estimate of the results of a proposed action can be obtained by use of this table. A closely related consideration is the reliability of the estimate.

A table of the type under discussion presumes knowledge on several important parameters of the radiation response of human beings. These are the slope of the dose mortality curve, representative of the distribution of sensitivities of the individual; and, probably of even greater importance, the actual value of the median lethal dose for man. At the present time these values are subject to considerable conjecture; for example, a recent report on the effects of ionizing radiation on human beings gives an estimate of the threshold dose for radiation lethality in humans of 225 r and an estimated median lethal dose of 350 r, considerably below the widely used estimate of 450 r.[2] On the other hand it has been variously suggested that this value might be as high as 550 r.

In addition to the uncertainty with regard to magnitude of the median lethal dose, we are also confronted with the lack of information on the other parameter necessary to describe the response of the exposed population to ionizing radiation. This is the slope of the curve describing the distribution of sensitivities to radiation. No reliable human data is available upon which we might base estimates of this slope. Figure 1 presents for comparison data on several mammalian species as well as the proposed human mortality distribution of Table 1. The slope of this line is a measure of the "spread" on the dose scale between the most sensitive individuals and the least sensitive. Characteristically in most well controlled studies of radiation mortality, this range is narrow. Even

Table 1

Estimated Medical Effects of Radiation Doses Expressed as Percentage of Working Force Affected*

Total Dose (r)	Duration of Continuous Exposure					
	1 Day	3 Days	1 Week	1 Month	3 Months	Effects
0 to 75	0% sick				0% sick	None.
100	2% sick	0% sick			0% sick	None.
125	15% sick	2% sick	0% sick		0% sick	None.
150	25% sick	10% sick	2% sick	0% sick	0% sick	None.
200	50% sick	25% sick	15% sick	2% sick	0% sick	Some late effects.
300	100% sick 20% die	60% sick 5% die	40% sick	15% sick	0% sick	Some late effects.
450	100% sick 50% die	100% sick 25% die	90% sick 15% die	50% sick	0-5% sick	Some late effects.
650	100% sick 95% die	100% sick 90% die	100% sick 40% die	80% sick 10% die	5-10% sick	Some late effects.

* This table applies to healthy, young adults under usual working conditions.
The percentage of fatalities will be decreased with adequate medical treatment.
The percentage figures are based on an interpretation of the best current available evidence and may be changed as more information is accumulated.

for mongrel dogs with a wide range of varieties of the species and poorly controlled age and weight, the slope is high. It would appear to be a reasonable conclusion that the human population would show a typically steeper slope than that assigned.

It is worth-while to consider further some of the properties of the generalized mortality-dose curve in order to evaluate its utility in predictive applications. The curve, as shown in Figure 1 is basically a cumulative frequency distribution of mortality as a function of dose. It has a long history of development and application in the testing of pharmacologic agents in the laboratory with the specific aim of improving the precision of estimate of effectiveness of the agent. Various transformations have been used to produce a linear regression of proportion affected upon dose. Of these the so-called "probit transformation" has been the most valuable. When the probit transformed response is plotted against the logarithm of dose, the linear plot shown in Figure 1 is the result. When this mathematical model is applied to laboratory data, the <u>specific</u> <u>aim</u> is to achieve an increased precision of estimate for the single parameter, medial lethal dose. In the course of laboratory measurement of lethality various responses are obtained for the dose levels used. To utilize all this data with the highest efficiency such a technique is applied. The output data, median lethal dose and its variance, are analogous to other techniques used for "averaging" experimental data, and, as in the latter, great care must be exercised in making inferences about data other than at the representative measurement of central tendency utilized.

In Figure 2 is drawn a typical logarithm of dose-response curve and dotted lines to indicate the precision of estimate. It is clearly evident that as one departs only a small distance from the central region, a high degree of uncertainty becomes attached to any inferences made from the data. As a matter of fact, it is a frequent laboratory observation that on rare occasions animals survive after very high doses or succumb after very low doses of ionizing radiation, in spite of a steep slope of the underlying mortality dose distribution.

As a corollary of the above, it is evident that tabular estimates of response at doses displaced from the median become increasingly unreliable. This is exactly what has been attempted in previous formulations of the acute radiation hazard. For example, in the OpNav Instruction referred to above, 100 r is given as the 2% effective dose and 125 r as the 25% effective dose for casualty production. Such application of the dose response relations is inconsistent with either the reliability of the data upon which the curve is constructed or the basic theoretical limitations on the system.

MODIFYING FACTORS

Other facets of present doctrine regarding effects of ionizing radiation that must be the subject of careful scrutiny are: (1) the modifications of acute effects by protraction of exposure, or more simply the implications of recovery upon the net biological effect, (2) the methods of considering exposures to mixed radiation, (3) the problems of effects of geometry of exposure such as partial body exposure or unilatetal vs. bilateral exposure, and (4) the reliability of the devices used in determining total dose. Each of these will be considered separately.

1. Recovery

It is presumed that recovery of a constant fraction of the injury remaining per unit time occurs, but with a residuum of injury that is non-recoverable. This exponential expression of recovery mathematically as first formulated by Blair[3] is written as follows:

$$D_e = D_o \left(f + (1-f)\, e^{-\beta t}\right)$$

where D_e is the effective dose, D_o is the physically measured total dose, f is the non-recoverable fraction of injury and β is the recovery constant. β has the dimensions of reciprocal time (t^{-1}) and has the significance of proportion of remaining recoverable injury per unit time.

Critical analysis of the recovery process depends upon precise estimates of the two constants of the above expression; f, the non-recuperable fraction and β, the recovery rate constant. Neither of these are well established for human beings subjected to ionizing radiation. Previously used values of β, or for example those applied in constructing the protracted exposure columns of Table 1, have been in the range of 0.10 - 0.20 day^{-1}. This corresponds to a period of 3 to 7 days for recovery of half of the injury. An implicit assumption in recovery application is that β, the recovery constant, is independent of dose and of previous radiation exposure history. Most recent information would seem to make these premises overly optimistic.

Estimates of recovery rates in man[4], and studies of others on the effects of total dose on recovery rates[5], indicate that certain adjustments in our use of recovery concepts must be made. The paper of Davidson has analyzed rates of recovery of leucocyte levels after single radiation exposure in many species including man. From the correlation of recovery rates and time for maximum depression of leucocyte count, he has predicted that the recovery constant for man is in the range of .02 - .025 per day for exposures below the lethal range. This estimate was rounded off to a "best estimate" of .001^{-hr} (0.1% per hour).

Vogel's report has demonstrated clearly that the recovery constant is not independent of total injury incurred, but is markedly depressed by doses of ionizing radiation in near lethal ranges.

Up to this point, we have given consideration only to that portion of the recovery formulation related to acute recovery rate, the constant β of the expression above. In protracted exposures the second constant, f, the non-recuperable fraction of injury, rapidly attains paramount importance. For this reason we must assess its validity as a generalized concept. Failure of recovery is conveniently divided into three distinct phases, each of which assumes more or less predominating roles under appropriate circumstances. The first of these, and the one most usually considered when a value of "f" is assigned, is that which we might call true irreparable damage which cannot be reversed and which causes a deficit in the capability to withstand further acute radiation stress. Brauer, Krebs, and Pessotti[6], as well as Blair[3] and others, have measured value of f in mice undergoing fractionated exposure to total doses of 1200 r and determined it to be 0.12 but most significantly, they warn that the value is not unique, but is dependent upon exposure sequence and other uncertain variables.

For animals undergoing continuous exposure another type of "irreparable" injury becomes manifest that we might call for lack of a better title <u>repair failure</u> or <u>delayed injury</u>. In animals subjected to continuous exposure at low levels the pattern is one of relatively complete maintenance of physiological adequacy for a long period followed by a sudden deterioration of this control with death resulting. For this delayed effects phase a unique value of f does not apply but rather it must assume a wide range of values approaching 1.0 in the limit.

The third phase of recovery failure is more generally referred to as the true <u>late effects</u> phase. After very protracted exposures or at long intervals after larger single exposures, specific pathological entities appear such as leukemia, lymphomata, skin cancers, other malignant tumors, as well as degenerative diseases of specific organs. For these effects specific recovery factors are required to describe each effect. As examples, it is quite clear that recovery is essentially non-existent for some radiation induced malignancies such as leukemia[7] while on the other hand the dose required for cataract formation may be dependent upon dose rate. Little specific information is available to us on the subject of recovery from most late effects.

There has been a repeated tendency on the part of users of the recovery expression to relate the non-recoverable residuum to equivalence with the delayed or late effects. As expressed in the recovery equation this non-recuperable fraction refers only to the first phase mentioned above, that is, the reduction in the exposed individuals' ability to resist subsequent acute radiation challenges.

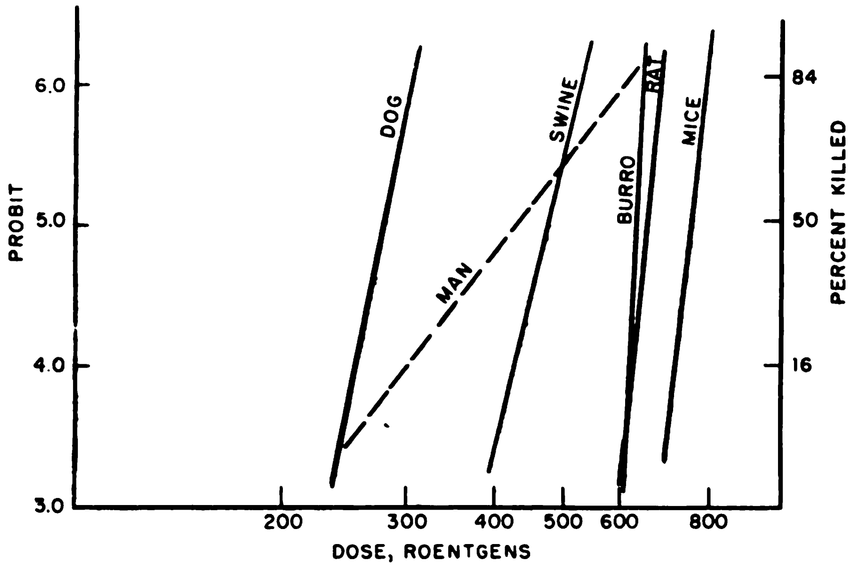

Fig. 1 Mortality - Dose Relationship for Various Species

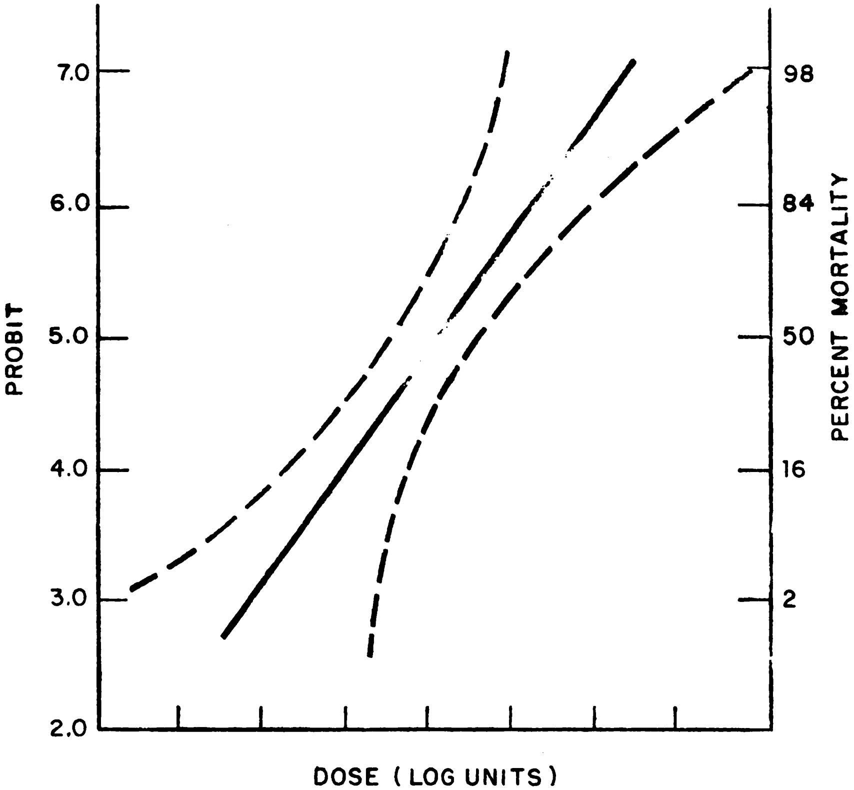

Fig. 2 Relationship between Response Level and Reliability of Estimate.

Confidence Limits for Response Curve Indicated by Dotted Lines.

Looking at the columns of Table 1 which give dose-effect data, we find that no consideration is given to all the variables mentioned above and that a recovery constant of approximately 20%/day has been applied. The result is an overly optimistic outlook on the effects of protracted exposure.

Recovery as a generalized concept has also been applied to the dose effects table at doses below the level where acute effects are significant. It must be borne in mind that recovery, as formulated, is a phenomenon related to reduction of the severity of an acute effects syndrome, and, moreover, the recovery constants available are all the result of work on animals where estimates have been based entirely on acute responses such as death or reduction of the white blood count. For this reason it is not practical when consideration is being given to the acceptance of doses in the non-acute range to allow an increase in acceptable limits based upon the assumption of partial recovery from protracted doses.

2. Mixed Radiations

In past experience it has been general practice to evaluate exposure to mixed radiations by means of the concept of dose in the unit rem. In this treatment the physical dose in rep is multiplied by an appropriate relative biological effectiveness ratio and is added to the dose of gamma radiation, for which an rbe of 1.0 is assigned, and a presumably cumulative dose is achieved which measures biological effect. Basically this concept is entirely sound, however, in practice there has been the serious practical difficulty of adopting the appropriate rbe for the system involved. For example, in one publication[8] neutron fluxes as a function of distance are given in rem while in the text the neutron rbe is variously quoted as 1-30 depending upon the end point. The user has no way of estimating the rbe used in constructing the flux-distance curve. The data under these conditions are of little specific value in computing total hazard from neutrons plus gamma rays. A recent report on rbe for acute effects in mammalian systems has summarized existing knowledge on effects of differences in specific ionization of various radiation.[9]

The rbe's for particles with specific ionizations ranging from that of 4 MEV gamma rays to that of fission nuclei varied only from roughly 1/2 up to 3. For neutron effects these values range from 1 to 1.7. This data was derived from studies on mice, therefore no effects arising from attenuating characteristics of the larger human corpus would appear. Depth dose curves for neutrons in the region of 0.5 to 2.5 MEV[10] lead to predicted midline to surface dose ratios of 1:50 for 0.5 MEV and 1:3 for 2.5 MEV neutrons. This consideration tends to lower "effective" rbe values for neutrons in this energy region to relatively low levels,

probably to values somewhat less than 0.5. Considering all other uncertainties an rbe of 1.0 for neutrons most certainly provides some factor of safety and leads to ease in computing combined hazard. This simplification would allow the presentation and direct application of neutron fluxes in terms of rep without calling upon the operator to make difficult decisions as to an applicable rbe.

The other significant radiation experienced in radiological defense is beta radiation. Two approaches have been made to this problem: (a) to assign an rbe and add the effect to the whole body gamma dose, or; (b) to assume that it is of limited importance and disregard it as a potential hazard. The first solution is impractical in light of the non penetrating character of beta rays and the fact that their important locus of action is the skin, while the second approach ignores the possibility that under certain circumstances beta radiation may be a controlling hazard.

3. Geometry Factors

All existing tables of radiobiological effects are based upon an assumed unilateral radiation of the whole body of the exposed individual. Two important factors can produce significant modification of the effectiveness of the radiation. The first of these is the geometry of the source with respect to the exposed individual. A wide range of source geometries is conceivable, from the point source distribution of prompt gamma radiation to the extended plane source radiating an individual when he is in the center of a fallout area unshielded by intervening structures. Various modifications between these extremes are also possible and likely. For example, in structures providing partial shielding or in cellars with little overhead shielding the radiation may radiate the whole body but come principally from overhead or underfoot. These variations in field are capable of producing differences in effectiveness of 30 to 50% between the two extremes, with unilateral radiation being the least effective and "ring-source" radiation being the most effective.

The second modifying factor is shielding of parts of the exposed individual. It has been shown by various investigators in laboratory animals, and has been a known fact of radiological therapy in humans, that much larger doses of radiation can be sustained when portions of the body are shielded. Of particular importance is shielding of regions containing active bone marrow. Regional shielding of as small a portion as the lower extremities is capable of producing a doubling of the lethal dose. Any technique used for estimations of biological response of the population either must make compensatory instrumental adjustments or must be sensitive to the variability introduced by these factors.

4. Instrumental Variability

Two recent experiments conducted at field tests have evaluated both operational radiac devices[11] and personnel dosimeters[12] for precision of estimate. Work has stated in his summary that "the project data indicate that errors as high as 50% can occur with carefully handled and calibrated instruments". The conclusions of Rainey and Duckworth are that "three factors discovered in the data of this report combine to render highly unreliable any tactical, medical, or administrative decisions which may be based on readings in the casualty range of single DT-60/PD or IM-107/PD dosimeters for personnel exposed during the fallout process and subjected to residual radiation on the weather decks of ships." Although this latter statement is somewhat more pessimistic than necessary it at least brings into critical focus the importance of realizing the shortcomings of present detector systems. Some improvement is no doubt necessary and will be accomplished, the physical limitations of the source-detector system will preclude measurements of the precision necessary for "level of response" type answers, i.e., percent casualties.

PART II

A PROPOSED APPROACH TO ESTIMATION OF RADIOBIOLOGICAL EFFECTS

INTRODUCTION

Generally speaking, estimation of the effects on personnel of an exposure to ionizing radiation are necessary for three purposes. These are:

1. Target analysis problems wherein it is necessary to make estimates of the response of a population to a given attack pattern for both offensive and defensive application.

2. Operational planning under emergency conditions where little or no dose control is possible and the primary decision is one involving completion or abandonment of a prescribed mission.

3. Operational planning in the recovery phase wherein some control of exposure is possible and time is available for organized radiological countermeasures.

One other general area might also be added involving operation under more routine radiological problems, such as operation of a contaminated facility when adequate countermeasures have reduced levels of exposure to acceptable wartime levels. This is an area with which we will not concern ourselves in this paper.

It is quite obvious that it is necessary to use different criteria for operation within these three major situations. Under category 1 it is possible to allow rather appreciable errors in estimating the lethal dose for individuals because with rapidly changing dose-rate contours only a small proportion of exposed individuals will be in the zone of uncertainty. For category 2 the whole unit for which a decision must be made may lie in the region of uncertainty and some feeling for the reliability of the decision which must be made should be available to the unit commander. For category 3, when adequate personnel are available, total exposures may be controlled below acute effects levels and exposure criteria must be associated with late radiation effects.

In the older approach, discussed in the previous section, the same basic set of effects data was applied in all of the above three situations. As the problems are more or less unique for each category some flexibility might be gained by altering the judgement criteria for the needs of the system.

GENERAL BASIS FOR APPROACH

Before making this subdivision it is probably worthwhile to first state a more or less unified concept of hazard and then adapt it to each situation.

When an individual is exposed to mixed ionizing radiations two specific organ systems are conceivably affected to an extent capable of causing either death or incapacitation. These organ systems are the bone-marrow-intestinal complex which may suffer physiological failure from the result of penetrating ionizing radiation; and the skin which can, as the result of the loss of its integrity, cause death or severe incapacitation. The latter organ can respond to radiation of all energies which penetrate to effective depths in the epithelium. If these are designated respectively deep effect and surface effect it is possible then to organize our thinking on the basis of two response criteria, one associated with the deep effect and one associated with surface effect. We shall refer to these as "deep hazard" and "surface hazard". They can be treated more or less independently in terms of acute effects as long as either one is relatively large with respect to the other. Data have been developed to show that the response to penetrating ionizing radiation is not detectably altered by superficial radiation as long as severe skin damage is not present.[13] In the presence of severe skin damage, on the other hand, it has been shown by Alpen, et al[15] and Brooks and Evans[14] that thermal burns of thirty percent or more of the body area reduce the X-ray LD_{50} appreciably.[14,15] Except for this limiting case we shall consider the two effects to be independent. When this assumption is made, an instrumental requirement is established for a detection device capable of assessing deep hazard independent of energy of the radiation

THE DEEP HAZARD

In Figure 3 is shown the relationship between the energy of the ionizing radiation and the dose effective in producing lethality in dogs. The data are for bilateral exposure to X-ray sources with rather broad energy bands, but it is reasonable to assume that only minor readjustments would need be made for more restricted energy limits. From the relative body and bone dimensions of dog and man it is possible to derive a curve of energy vs. effectiveness for lethality in man. This curve is also shown in the same figure. For estimation of hazard the instrument used in measuring dose, either portable radiac, pocket dosimeters or film badges should have a sensitivity which is reciprocal to this curve. We might state the requirement as follows. The instrument must have unit sensitivity for gamma radiation above approximately 80 KEV. At 30 KEV the sensitivity must be reduced to 50% of the maximum and it must detect no more than 1% of the gamma radiation of 15 KEV or less.

The principal basis for this requirement is the need to appropriately weigh whatever small amount of low energy gamma radiation is present, and, of much greater importance, to insure that none of the beta radiation present in the same environment is measured.

It has been mentioned in preceding sections that when radiation is from an extended plane surface or a ring type source that on the purely physical basis of depth dose enhancement the radiation will be 20 to 30% more effective than unilateral radiation at the same total dose. With this consideration in mind it is necessary to adjust the dose levels which will be predicted to yield a given response and also to require a geometrical responsiveness within the instrument that yields equal meter deflection for radiation from any angle. It has been shown that existing instrumentation is seriously deficient in this latter regard. Work[11] has shown that the shielding of the detector provided by the instrument case and the operator leads to a drop in detection sensitivity in the rearward quadrant. It seems that one of the more pressing requirements in radiac development at this time is correction of this deficiency.

Assuming that the requirements of energy and geometrical dependency of sensitivity are met in the detector, it remains for us to establish a series of standards of biological response that might be useful in implementing the three problems outlined in the previous section.

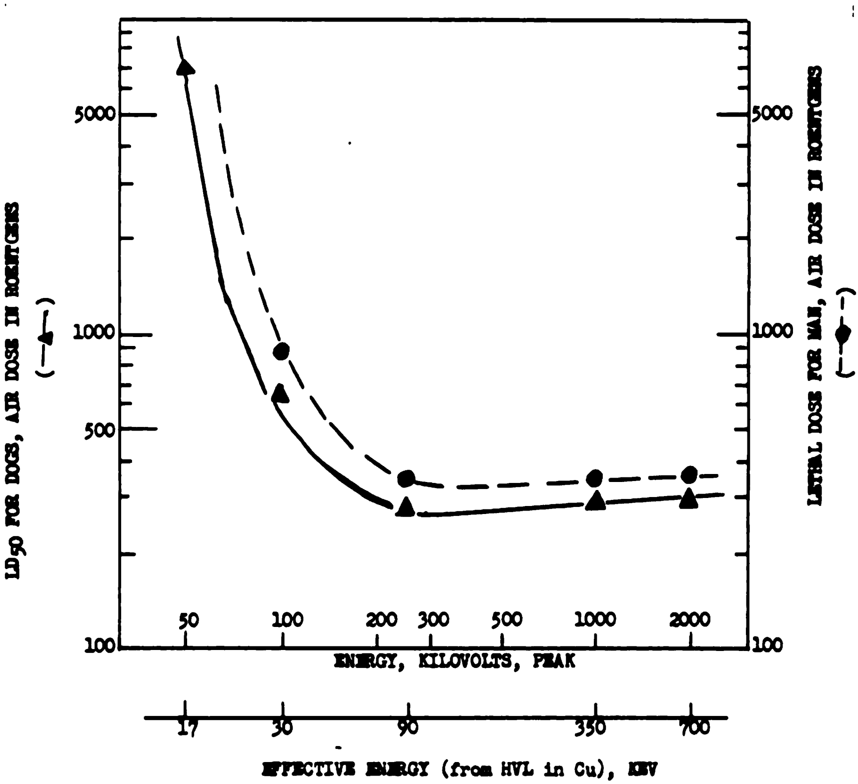

Fig. 3 Lethality of Ionising Radiation as Related to Energy.

Solid line connects measured values of the LD_{50} for dogs, bilateral radiation. The dotted line connects the estimated values for man assuming a phantom thickness of 27 cm and an average bone thickness for marrow shielding of twice the value which would be found in the dog.

After the careful consideration we have made previously of the methods presently applied in problems of radiobiological response of human beings, it seems certain that an unwarranted degree of precision has been assumed in these estimates. It is our aim to establish criteria more consistent with present certainty of knowledge, and to bring up to date application of concepts of recovery, geometry effects, partial body exposure, and long term hazard.

The first subdivision of the deep effect hazard can be made with respect to the acute vs. late effects. If no significant accute effects occur up to whole body doses of approximately 150 r then this is clearly a point on the dose scale at which a change in approach must be made. It is of no real significance to tabulate dose limitations for acute effects below this point. From the analytical point of view it is relatively simple to formulate the hazard statement for exposures at total doses below 150 r. It is a generally accepted hypothesis in radiation biology that recovery rates for most long term or delayed effects and for transmissible genetic faults are zero or very nearly so. As a corrollary to that postulate the incidence of these effects must be linearly related to total exposure. With these two concepts in mind we can then say that the hazards of exposure to doses below 150 r of whole body radiation is linearly related to this dose. Although it is difficult for us to assign a primary hazard value to 150 r we can state that when we are working in this dose range any exposure less than this value either in one dose or over a protracted period results in the incurring of a linear fraction of this maximum hazard. For example, 75 r is half as likely as 150 r to produce serious late consequences. It must be clearly borne in mind that the hazard associated with 150 r is a very serious one, not to be approached without careful consideration of the consequences.

Having established the relationship that hazard is linearly related to dose up to the point of incurring acute effects, we can also elaborate on the time relationships for this exposure. All modern concepts of maximum permissible exposure for peacetime application are based upon the "budgeting" of radiation in such a fashion that over a prospective life span we will not exceed some maximum dose. Implicit in this argument is the non-existence of recovery, and when the basic rate or weekly maximum permissible exposure is abrogated, maximum exposures are fixed by the maximal acute effects which are acceptable under the circumstances. For instance in emergency peacetime applications the acute effect limitation may be set as that dose which causes detectable decreases in peripheral leucocyte counts. Complementary to this reasoning is the statement that formulae for protraction in time of emergency MPE at levels below that causing an acute response result in no ultimate gain in safety. For example, if an operational peacetime MPE is set at 3.9 r total for a complete operation, the period in which it is accepted does not influence the resultant hazard.

The formulation of delayed hazard presented above for the 0 - 150 r zone is no more than an extension of current doctrine, as it has just been restated, to the most serious of circumstances. For this most serious situation the limiting acute effect is incapacitation of the work force. Consideration must be given at the end of the emergency period to life time total exposure of the individual, and if possible, a person receiving 150 r should be restricted in exposure to radiation above background levels during the remainder of his life span.

Recovery of the individual from the acute effects of exposure would allow raising the 150 r ceiling somewhat but considering the uncertainty associated with the instrumental measurement of dose and the long range danger of accepting 150 r it is recommended that this limit not be adjusted upward.

Acute Effects

When a dose of 150 r is exceeded, the problem of prediction of the result of such exposure becomes more difficult. It was pointed out in Section I that serious doubts exist as to the validity of any approach to acute effects which purports to estimate the fraction of the work force either incapacitated or dead as the result of a given exposure. The variables mentioned were: uncertainty as to the true LD_{50} for man; uncertainty as to the distribution of sensitivity of the population; uncertainty as to instrumental measurement of true dose; uncertainty as to approximating to whole body exposure for the exposed population.

In addition, it has also already been remarked that if all of the above parameters were known adequately it is still a property of any dose response curve that estimates of proportions responding at dose levels far from the mid-lethal level are made with a low degree of confidence.

To avoid the implicit and unwarranted precision involved in the older formulation alternatively it is suggested that a tabulation of "zones of effect" is the most feasible approach, considering the present state of knowledge of effects of radiation on man. Such a tabulation is presented in Table 2. On the left are the dose regions for the predicted effect when the time of exposure is from 24 hours to 1 week.

Table 2

ACUTE EFFECTS OF WHOLE BODY PENETRATING IONIZING RADIATION ON HUMAN BEINGS

Dose in <1 week	Effect
0-150 r	No acute effects - serious long term hazard.
150-250 r	Nausea and vomiting within 24 hours, minimal incapacitation after 2 days.
250-350 r	Nausea and vomiting in under 4 hours. Some mortality may occur in 2-4 weeks. Symptom-free period 48 hours to 2 weeks.
350-600 r	Nausea and vomiting under 2 hours. Mortality certain in 2-4 weeks. Incapacitation prolonged.
> 600 r	Nausea and vomiting almost immediately. Mortality in 1 week

If a value of 0.025 day^{-1} for the recovery constant and of 0.10 for the non-recuperable fraction are applied, consistent with the deductions of Davidson mentioned earlier, biological recovery is not of significance during a 1 week protracted exposure. It must be borne in mind however that for exposures extending over a period of more than a few hours the temporal relationships will be modified somewhat from those shown. That is to say, a dose of 250-350 r given in three days will most certainly not produce nausea in 4 hours.

In the past it has been a practice to present adjusted total dose values for protracted exposures of 3 days, 1 week, 1 month, etc. Two serious short-comings of this sort of an attempt are to be found in the assumptions that: (a) recovery will not be affected by dose rate and can be estimated by an average exposure rate during the period; and (b) that the acute radiation syndrome is unaltered by protraction of the dose over long periods. The discussion of recovery in Section I has pointed out the complexities involved in the recovery mechanism under various dose rates or fractionation patterns. The oversimplification inherent in protracted exposure-effects tables make them of very limited usefulness.

In spite of these difficulties it is probably worthwhile to refine our judgment of biological results with some sort of recovery correction. As most exposures will occur in a rapidly changing dose rate field it is most worthwhile to use the approach of several workers[1] and most recently Davidson[4], who have plotted "effective dose" vs. time of entry and departure in a fallout field. It is significant that for early entry times, i.e., up to +24 hours, accumulated physical dose and calculated biologically effective dose do not differ appreciably until total exposure is in excess of several hundred hours. It is the recommendation of this report that for the three functions outlined at the start of this section that biological recovery should be considered as contributing very little to force effectiveness in the acute dosage region. For more exacting problems such as protracted living in contaminated areas or for prolonged recovery operations in controlled situations it is recommended that computational techniques similar to those mentioned be applied to meet the specific needs. A recovery constant of .025 day^{-1} and a non recoverable fraction of 0.10 are suggested for this purpose. A clear appreciation for the limitations of the calculation should accompany its application.

Protective Influences

It is patently impossible to construct a table of effects that would incorporate all possible combinations of general external shielding, partial body shielding and exposure geometry. However, it is within the capability of the operator to apply some general "rule of thumb" protection adjustments to correct for these factors. Some of these are already obvious and have been utilized in the past. General external body shielding can be adjusted for by multiplying the dose rate by shielding factors provided or by multiplying the permissible exposure by the reciprocal of this value. A reduction of about one-third to one-half in the effectiveness of radiation can be made when partial body shielding of a major portion of the trunk is involved. For unilateral exposures a similar reduction of about 20 to 30% is allowable. It is suggested that all of these be accumulated into a single protection factor and accumulated physical dose adjusted accordingly.

THE SURFACE HAZARD

A good deal of comment has been accumulated in the past with regard to the relative hazards associated with the beta radiation hazard (Med. Off. Handbook, NavMed P1330, June '51,[1,8,16]) which run the gamut from

its complete exclusion from the hazard picture to the assignment of a primary role in hazard analysis. It seems relatively certain with the experience gathered at nuclear tests over the years that the hazard to the body surface is usually not a limiting one. However, there are certain conditions when limitations of exposure of the skin might be a deciding factor. The following will attempt to demonstrate the most significant of these situations.

Instrumental detection of beta radiation under field conditions has usually relied upon a constant or slowly changing ratio of beta to gamma radiation. If the gamma dose rate is known the beta dose rate is estimated by multiplying by an appropriate factor, usually near 10. In an extended plane source of distributed fission products on the ground the contributions to the gamma radiation dose rate arise from as far as several hundred meters from the detector while the beta dose contributions can come from a radius of only a meter or two from the detector. Assuming a beta/gamma ratio of 10 for the extended source then any restriction of the "field of view" which does not disturb the proximal 1-2 meter circle causes an increase in this ratio. As the restriction is carried to the limit the ratio becomes overwhelming. Actual examples of this situation are individuals working alongside shielding walls, in revetments providing shielding from three sides, or on board vessels with restricted surfaces for fallout collection.

Another obvious situation where beta radiation is significant is the one in which a large contaminated object is removed from a fallout field. In this case beta-gamma ratios cannot be relied upon for meaningful estimates of surfase dose rate.

THE NATURE OF THE SURFACE HAZARD

The primary radiation sensitive system within skin is that layer of cells (the basal layer) which is constantly dividing to replace the aging epidermis. Wilhelmy[17], and Moritz and Henriques[18], and Alpen and Shumway[19] have all shown that the radiobiological response of skin can be estimated without correction for energy of the radiation if the dose is measured at a depth equivalent to 7-10 mg/cm^2 and with a detector volume equivalent to 1 mg/cm^2. It must be borne in mind that all ionization reaching this point in skin is effective in producing damage, hence it is imperative that the detector measure <u>both</u> beta and gamma for total <u>surface hazard dose</u>. If these conditions of measurement are met the indicated dose rate can be used for a direct estimate of hazard to skin.

QUANTITATIVE ASPECTS

The nature of the radiation "field" which can cause damage to skin has been subdivided into two specific types which have been variously characterized in the past but which recently have acquired the more or less descriptive titles of "bath hazard" and "contact hazard". The bath hazard is associated with radiation from material deposited on the ground. The contact hazard is associated with radiating material deposited on skin.

It is close to impossible to predict which of these will be the ruling hazard with the limited knowledge available at this time, but there are certain conditions where clearly one or the other may prevail so that it would be extremely desirable to incorporate capabilities for estimating both hazards in any instrument designed for surface hazard evaluation.

As the subject of radiation effects on skin are less well known than whole body effects, Table 3 is included as a summary of surface effects with the best existing information as to estimated dose required (EDR).

Table 3

BIOLOGICAL EFFECTS OF RADIATION ON THE SKIN

Effects of beta radiation are of four types:

a. Immediate — appearing from 0 to 48 hours after exposure

1. Erythema (reddening of the skin, as in severe sunburn) and itching. Estimated dose required (EDR): 600-1000 rads. If 600 rads, will probably appear within 48 hours; if 1000 rads will probably appear within 24 hours.

2. Vesication (formation of blisters). EDR: between 30,000 and 100,000 rads.

b. Delayed — appearing from one to five weeks after irradiation.

1. Second wave erythema. EDR: 600-1000 rads.

2. Vesication and Desquamation (loss of skin). EDR: 2500 rad.

3. Epilation (loss of hair). EDR: 300-700 rads. Not significant operationally.

c. Persistent Changes

1. Radiation Dermatitis. Persistent ulceration in which skin repeatedly breaks down. Requires replacement of skin. EDR: more than 600-1000 rads.

2. Vascular Changes. Visible spiderwebbing of surface veins. May contribute to dermatitis. If not, not operationally important. EDR: 500 rads, to the blood vessels.

3. Atrophic Changes. Skin becomes very thin and easily damaged. No estimate as to EDR.

d. Long Term — appearing after one year.

1. Tumor induction. EDR: 1000-2000 rads. A statistically significant increase in tumors has occurred in irradiated animals. Not predictable on an individual basis. A genetic effect at the cellular level.

2. Less Severe Radiation Dermatitis. No estimate as to EDR.

3. Cataract formation. EDR: 2000 rads to lens.

Given the data presented in Table 3 it is possible to construct an operational table similar to that formulated for deep hazard. Again it is possible to divide the dose range into two regions using the same criteria as were applied for the deep hazard. If severe erythema is accepted as the acute effect which will incapacitate, then a dose of 600 rad is set as the upper limit for operation based upon the criteria of maximum acceptable acute effects. The same reasoning holds as for the 9-150 r region of deep effects. Hazard is linearly proportional to accumulated dose up to this maximum figure. For doses over 600 rad the following table should be applied in accepting or rejecting maximum exposure levels.

Table 4

ACUTE EFFECTS OF IONIZING RADIATION ON SKIN

Estimated Dose Required (EDR) in < 1 week	Effect
0-600 rad	No acute effects.
600-2000 rad	Moderate early erythema.
2000-4000 rad	Early erythema under 24 hours. Skin breakdown in 2 weeks.
4000-10,000 rad	Severe erythema in < 24 hours. Severe skin breakdown in 1-2 weeks.
10,000-30,000 rad	Severe erythema in < 4 hours. Severe skin breakdown in 1-2 weeks.
30-100,000 rad	Immediate skin blistering (less than 1 day).

Modifying Factors

Recovery rates for skin are as yet not extensively determined but one published report on rat skin[20] indicates that recovery is probably more rapid for skin than for deep effects. No information is available

as to permanent non-recoverable fraction. As a rule of thumb it is probable that a factor of 2 could be applied to the above tabulated values to get equivalent EDR's for 1 month exposure. The same remark is appropriate here that was mentioned under deep effects; the time schedule indicated in the table will not hold for protracted radiation.

Shielding is of critical significance for protection from the surface hazard. The dose rate to clothed surfaces of the body will be appreciably reduced by the shielding afforded by the covering. Condit, Dyson and Lamb[21] have measured the absorber characteristics of several military uniform fabrics as shown in Table 5.

Table 5

ABSORBER CHARACTERISTICS OF FABRICS

Material	Wt/unit Area
Denim work pants	31 mg/cm^2
Cotton work shirt	17
Woolen pants	34
Knitted wool (sweater)	31
Close woven rayon	6.3

A normal two layer fatigue uniform would have absorption characteristics approaching one half-value layer for mixed fission products. Heavy clothing will be equivalent to roughly two half-value layers. Protection factors of 0.5 and 0.25 are then applicable to measured dose rate for areas covered with clothing.

Attenuation in air of beta radiation providea protection for upper portions of the body. However, direct measurement of the dose rate at the point of interest makes the necessary correction for this variable.

PART III

APPLICATION OF PRINCIPLES

Now that a general statement of hazard has been delineated, let us consider the application of these principles to the three types of decision problems described previously. We shall consider each independently to find the most profitable modifications of the general plan.

1. Target Analysis Problem

In this problem we are applying the standards set up to a large sample in a situation where physical input data is not well established. It seems that there would be no loss in precision if for this problem the concept of the "estimated dose required" were carried to the extreme of simplification. Considering the rather poor input data as to expected dose rates, and the small proportion of the sample involved in the critical dose area, two EDR's are proposed: one, the estimated effective dose to produce sickness in 24 hours; and the other, the estimated effective dose for lethality. Proposed values for these are: $EDR_{(sick)}$ 200 r and $EDR_{(dead)}$ 400 r. The dose should include the estimated prompt gamma dose, the residual gamma dose and the neutron dose in rep with no correction of the latter for rbe.

It is expected that insofar as the input data allow, corrections would be made for protection factors as outlined above.

The surface hazard should not be considered in an analysis of this type.

2. Operational Decisions Under Emergency Conditions

When the primary decision to be made involves completion or abandonment of a prescribed mission, the best guideline available for this decision is within the table of "zones of effect" for deep hazard. This is clearly the area in which late hazard and skin hazard can play only a minor modifying role. The table provides guidelines for the commander as to what he might expect of his available force during the period of necessary availability. For example, if his instrumental information predicts an accumulation of 220 r (combined deep dose, i.e., gamma + neutron) during a subsequent three day period he will assume from the table that serious incapacitation will result during the interval, while if the dose exceeds 250 r he will expect to sustain serious losses. Of

course it is obvious that instrumental information is subject to error but some conservativeness in the doses shown in the effect table will prevent catastropic errors from occurring except on infrequent occasions.

Again in this decision problem, the surface hazard should be considered only when some unique alteration of exposure conditions such as a heavily contaminated naval vessel in uncontaminated water makes its importance overwhelming. Even under these conditions the surface hazard will usually not be a threat to life, so that under emergency stress where casualties are acceptable it should receive only minimal consideration.

3. Operational Decisions in the Recovery Phase.

Insofar as the circumstances allow, exposures during this phase should be restricted to the late effects area, i.e., under 150 r for deep hazard and under 600 rad for surface hazard. As long as the realization exists that long term hazard to the individual is increasing in direct proportion to the exposure, competent judgment can be made for any radiological situation.

If necessity demands entering the area of acute effects both deep and surface hazard must be evaluated and final determination of course of action must be based upon the limiting hazard.

As indicated before, recovery for periods under two weeks will not be a significant modifying factor. If operations will extend over prolonged periods, i.e., in excess of one month, some computational technique should be applied to modify the dose levels allowable. Again, at the risk of palling repetition, it must be remembered that no recovery correction is applicable for late effects. Either Davidson's[4] formulation based on a recovery constant of .025 day^{-1} and a residual of 0.10 or some modification is suggested for recovery calculation.

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Representative HOLIFIELD. Our next witness will be Col. J. B. Hartgering, U.S. Army Medical Corps, and he will discuss the actual laboratory findings of the accumulation of fission products in man. He has participated extensively in the radiological safety aspects of the atomic weapons program.

He has served as the Chief of the Department of Biophysics and the Director of the Division of Nuclear Medicine and Chemistry at the Walter Reed Army Medical Center, and is now serving as the Chief of the Biological and Medical Science Branch of the Army Research Office.

TESTIMONY OF LT. COL. JAMES B. HARTGERING,[1] M.D., U.S.A., WALTER REED ARMY MEDICAL CENTER, WASHINGTON, D.C., ACCOMPANIED BY CAPT. HARRY CLAYPOOL, M.C., U.S.A.

Colonel HARTGERING. Mr. Chairman, members of the committee, in the interest of time I will try to summarize the written material that I submitted to you.

Representative HOLIFIELD. We will appreciate that, sir, and that is no reflection on the importance of this. We know you probably have had more experience in measuring humans, in this field, than any other man in the world. So we hope you will not shorten your statement to the point that you leave out the important things that should go in. We will put your whole statement in the record.

(Colonel Hartgering's prepared papers follows:)

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THE ACCUMULATION OF FISSION PRODUCTS IN MAN

J. B. Hartgering

INTRODUCTION

The detonation of multiple high yield nuclear weapons will contaminate the earth's biosphere with more than two hundred radionuclides as a result of the fissioning of uranium or plutonium plus a few nuclides secondary to the fusion process. Complex meterological and geophysical factors, as discussed by others at these Hearings, will affect the amount of radioactivity available for assimilation into the various segments of the world's population. Stated simply the problem is to determine which fission fragments are deposited in man, define the biological effects of various levels of activity, and consider possible counter measures.

International concern over fallout from weapons test programs has stimulated extensive fundamental research as well as continuing measurements of the levels of several fission products accumulating in man. Most of the data has been summarized or referenced in excellent official United States (1)(2)(3), British (4), and United Nations documents. However, it is perhaps pertinent to point out these studies were largely confined to very low levels of radioactivity - at least when compared to those expected in a nuclear war. Further, the medical aspects of nuclear warfare must consider all of man's environmental stresses, as these may influence his response to the total ionizing radiation exposure.

HUMAN RADIOBIOLOGY

For the past six years the Walter Reed Army Institute of Research has conducted extensive surveys of world wide fallout. These were summarized in 1957 (2). In 1954, with the assistance of the United States Atomic Energy

Commission, a long term study of fission products assimilated by the Marshallese following the 1 March 1954 test was initiated. The details of this five year study are included as Appendix 1. In the past year with the cooperation of Dr. E. L. Anderson of Los Alamos, a Human Counter Facility was completed at the Walter Reed Army Medical Center. Data from a survey of over twelve hundred individuals are included as Appendix 2. In May 1959, the Geneva Human Counter constructed by Los Alamos for the recent Atoms for Peace Conference was placed in operation by the United States Army in Germany.

Based on these data and selected applicable human studies conducted by others (5)(6)(7), certain practical aspects of the internal deposition of fission products in man may be summarized:

a. Fission products enter the body with the ingestion of food and water and by inhalation.

b. Several radionuclides have been detected including strontium-89, strontium-90, cesium-137, cesium-144, praseodymium-144, barium-140-lanthimum-140, several isotopes of iodine, zinc-65, cobalt-60, and in one instance plutonium-239.

c. In unprotected populations exposed to fallout soon after a detonation, the internal hazard is minimal compared to the external gamma exposure. Therefore, no immediate casualties are expected due to internally deposited radioactivity. A possible exception involves individuals in deep shelters without protective air filtration. Iodine activity may be sufficient to cause hypothyroidism in a few weeks. Otherwise medical effects will only become apparent after months or years.

d. Nuclides with long half lives may remain in the soil and be available for incorporation into foodstuffs for years.

e. The level of radioactivity in contemporary man is known and can be generally correlated with fission product production to date.

The detailed data obtained to establish the above generalization can be utilized to determine the potential levels of radioactivity associated with any particular nuclear attack pattern.

The possible medical effects of various amounts of mixed fission products deposited in man are not as well understood. Uncertainties are greater by more than an order of magnitude. For any individual nuclide, human injury will be related to; the amount of radiation and its characteristics including half life, biological half life (time for fifty percent excretion), and the site of deposition within the body. The essential biological information is available for only a few isotopes. No human data reflects the possible effect of multi-millicurie levels of several isotopes deposited simultaneously within the body. Estimates are usually based on the "most hazardous single isotope" and predictions made as to the amount of gastro-intestinal damage or the probable incidence of cancer at some later date assuming that the combined effects of several isotopes are simply additive. Some experiments in mammals have shown, however, synergistic effects (8).

Thus all estimates must be based on extrapolations from animal experiments. Variations in life span, physical size, metabolic rates and fundamental biochemistry will of necessity introduce large uncertainties. An example is the recent adjustment in cesium-137 tolerance by The National Committee on Radiation Protection. This reflects in part human experiments demonstrating that the biological half life is approximately eight times longer than estimated from rodent data. Further, except for accidents and a few volunteer studies human data has been obtained by following single

acute doses rather than repeated or continuous exposures. The latter in the case of strontium-85 results, in a significantly, decreased excretion rate (9).

COUNTERMEASURES

Previous comments have assumed an unprotected population. Practical but exacting and time consuming countermeasures should markedly reduce the potential hazard. During active fallout, shelters provided with particulate filters or individual masks will eliminate inhalation of fission products. Processed food can be readily decontaminated, but the volume of drinking water required by a population can be only partially cleared of activity. The usual city filtration systems are inadequate as some important radionuclides including strontium-90 are soluble (10).

Agricultural inspection of new crops may be required for several harvests. Uncontaminated acreage or that with minimal activity should be used if possible, but if not available proper crop selections may minimize the uptake of soil contamination.

In addition to these primarily physical measures, the potential of medical prophylactic drugs and treatment may be useful. In 1958, Jacobus at the Walter Reed Army Institute of Research demonstrated for the first time that large animals could be protected by oral administration of certain chemicals from otherwise 99 percent lethal radiation. The Department of Defense provided 1.6 million dollars of emergency funds to exploit this research. Medication which will minimize the effects of radiation in man is not available today, but the initial research is accomplished.

CONCLUSIONS

The deposition of fission products in man will not result in casualties in the early phases of a nuclear war, but the potential accumulation during post attack recovery is a real threat, and will require positive countermeasures. These can be developed and maximized provided basic research in human and mammalian radiobiology, decontamination, and the techniques of measuring radioactivity in man are exploited.

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The Determination of Internally Deposited Radioactive Isotopes in the Marshallese People by Excretion Analysis*

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INTRODUCTION.

Following the detonation of a thermonuclear device at the Pacific Test Site on 1 March 1954, 239 Marshallese people were exposed to significant levels of gamma radiation from fallout. Estimated total exposures ranged from 175r on Rongelap to 14r on Utirik (1).

These populations were evacuated to Kwajalein for decontamination and care. During the two days of fallout exposure before evacuation was completed, the Marshallese also received some radioactive materials internally by ingestion and inhalation. Estimates of the internal body burden from fallout were obtained from the analysis (1) of urine samples collected soon after exposure.

These data indicated that the acute hazard from internally deposited fission fragments was quite small as compared to the whole body gamma radiation exposure. Although the radioactivity levels in the urine were low, the activity was sufficient to obtain reasonable precision and to warrant additional long term studies of the activity levels and excretion patterns of this rather large and well isolated population.

The people from Alinginae and Utirik were returned to their home islands in June 1954. Radiation intensities on Rongelap, however, precluded an early return to this atoll and the Rongelap people lived on Majuro from June 1954 until July 1957.

Basic data on the food crops of the Marshallese indicated that after resettlement on the contaminated atolls the intake of strontium^{90} would be increased considerably, and that cesium^{137}, zinc^{65}, and cobalt^{60} were dietary constituents of island and ocean foodstuffs, and also would be assimilated (2). The expected increases in the trace amounts of radionuclides in the food supply of a large population would afford an opportunity to investigate the rate of equilibration and the discrimination factors operating between food supply and man. Urinary

excretion levels of cesium^{137} and strontium^{90} were measured from March 1954 through March 1958. Zinc^{65} levels were first measured in 1958 samples.

MATERIALS AND METHODS.

One hundred and forty one individual urine samples collected from 24 March 1954 through 7 September 1954 were obtained by the Health and Safety Laboratory, AEC. Urine volumes were small (about 350 ml) and it was necessary to pool samples. This was done according to the age of the subjects and 19 samples of pooled urine were assayed. A 57 liter pooled urine sample from Rongelap was collected and assayed in 1956 (3). Three pooled samples and seven individual samples were assayed in 1957. Thirty individual urine samples were assayed in 1958.

In samples collected in 1954 and 1957 cesium^{137} was scavanged by nickel ferrocyanide (urine made strongly alkaline) and counted in a crystal well counter. A twenty channel gamma-ray spectrum was determined for each sample and the cesium^{137} photo spectrum count rate used. The 1958 samples were assayed directly for Cs^{137}, Zn^{65}, and K^{40} in 2.5 liter plastic containers placed on an 8 x 4 inch (TH activated) sodium iodide crystal. The activity for each radio-isotope was determined by gamma-ray spectral analysis. Sample activities were compared with known radioactive standards (± 5 percent) counted in the same geometry.

Strontium^{90} was precipitated from urine as the carbonate. Yttrium^{90} was separated and identified by its half-life using thin walled gas flow counters.

Urine samples were corrected for radio-active decay to the time of collection.

There is some uncertainty as to the completeness and the duration of time over which samples were collected and therefore twenty-four hour urine volumes are not accurately known. Potassium^{40} excretion, using 360 d/m or 2 gm K/day indicates an average daily volume of about 1180 ml (± 56 percent). It was convenient to use one liter as an average 24 hour urine volume and to express radioassays in micromicrocuries per liter.

RESULTS AND DISCUSSION.

Cesium^{137} Excretion Levels and Body Burden

The urinary excretion levels of cesium^{137} for the years 1954, 1957, and 1958 are shown in Tables 1 - 4. On 24 - 25 March, 1954, the mean excretion level of cesium^{137} for all age groups was 405 uuc per liter. With an excretion rate of 0.46 percent (4) of cesium^{137} body burden per 24 hours, the mean body burden from fallout 24 - 25 days after exposure was $405/4.6 \times 10^{-3} \times 10^{6}$ or 88 muc (± 54 percent). This value is about 20 times the average body burden reported by E. C. Anderson, et al (5, 6) for people measured during 1956 - 1957 in the United States. The cesium^{137} urinary excretion levels for the six months following exposure can be expressed as an exponential function, and a best line of fit drawn through the data resulted in a half time for elimination of about 110 days (Fig 1). A biological half time of about 140 days has been observed on volunteers who ingested one microcurie of radio-cesium (4).

From the 1957 Cs^{137} excretion levels (Table 2) the Rongelap group exposed to fallout was estimated to have an average burden of about 7 muc, whereas the Rongelap control group was about 2 muc. Body burden in either group in 1957 is comparable to levels measured in the U. S. population (6). With a half time for elimination of the order of 150 days, the body burden of the exposed Rongelap group should have decreased from the March 1954 level to 7 muc in about 550 days, or late in 1955. A body burden of 7 muc for this group in March 1957 could then indicate a continuing exposure to Cs^{137} during 1956 of the order of 32 micro-microcuries per day from stratospheric-tropospheric fallout while residing on Majuro.

Since the Utirik group was returned to their atoll in 1954, the mean body burden in 1957 was elevated to an estimated 337 muc, some 48 times the Cs^{137} burden of the exposed Rongelap people who resided on Majuro. This long residency time on Utirik atoll after fallout contamination, as compared to the excretion

rate of Cs^{137} should have resulted in an equilibrated Cs^{137} burden, with an estimated daily intake of about 1560 uuc of Cs^{137}. Unfortunately no systematic survey of foodstuffs grown on these atolls has been reported. Data available, however show that coconut grown on Rongelap contained about 9 uuc Cs^{137} per gram, and arrowroot (Utirik) contained about 8 uuc Cs^{137} per gram. The daily intake of several hundred grams of either staple would be sufficient to account for the 1957 excretion level in the Utirik group.

The Rongelap groups had been resettled for about nine months at the time of the March 1958 medical survey, and urinary excretion levels of Cs^{137} had increased about one hundred fold over 1957 levels. Mean body burden for the two groups at this time was 0.9 uc (± 27 percent) and 1.2 uc (± 47 percent) (Tables 3 and 4). $Cesium^{137}$ body burden may have equilibrated by late 1958 and predicted burdens were about 1.3 and 1.6 uc respectively

Strontium^{90} Excretion Levels and Body Burden

Urinary excretion levels of strontium^{90} are presented in Tables 1, 2, and 3. The strontium^{90} excretion level in 1956 was 0.5 uuc/liter as determined in a pooled sample of 57 liters Figure 2 shows the excretion of Sr^{90} for the three years following fallout exposure. Although there is considerable variation in the data for the various age groups at early times, mean values for all groups plotted suggest that the excretion pattern can be expressed conveniently as the sum of two exponential terms The larger portion of Sr^{90} was excreted with a half time of about 40 days, and a small fraction, 20 percent, was excreted with a half time of about 500 days. This is similar to Cowan's (7) urinary excretion study of an accident case involving inhaled Sr^{90}.

As was noted in the March 1958 Cs^{137} levels, the excretion levels of Sr^{90} were also increased to 3.5-4.0/0.2, or about 20 fold. Since Cs^{137} levels increased 4300 - 5300/34, or about 140 fold, the ratio is about seven in favor of cesium^{137}. With the increases in urinary Sr^{90} excretion levels in 1958, it was

pertinent to estimate body burden, burden expected at equilibrium, and daily intake of Sr^{90} from these excretion levels.

The metabolic behavior of strontium as outlined in Supplement #6 of the British Journal of Radiology was used to estimate body burden, etc. from urinary excretion levels of $strontium^{90}$ (Appendix). The fraction of strontium absorbed from the gastro-intestinal tract is 0.6 and the biological excretion rate from the total body is 190 days. Of the absorbed fraction, 0.25/0.60, about 42 percent is deposited in bone and the biological half-life is 4000 days. Assuming that the absorbed fraction is excreted entirely in urine, the mean body burden of the exposed Rongelap group in March 1958 was 2 muc (± 52 percent). This is about nine percent of the expected equilibrium value of 23 muc. The estimated burden of $strontium^{90}$ for March 1958 is probably too low and compares with levels measured in stillborn children in the U. S. several years ago (8). The daily intake of $strontium^{90}$ is estimated to be about 15 micromicrocuries or 15 Sunshine Units (assuming a daily calcium intake of one gram).

Dunning (2) reported that the average concentration of $strontium^{90}$ in the Marshallese food supply could be about 360 Sunshine Units, but this would reduce to well under 100 Sunshine Units if the consumption of high Sr^{90} content foods were eliminated. With the elimination of pandanus and land crabs the diet used by Dunning indicated that the intake of $strontium^{90}$ would be 17 Sunshine Units per day. This compares favorably with the estimated intake of about 15 micromicrocuries from excretion analysis.

<u>$Zinc^{65}$ Excretion Levels and Body Burden</u>

In early 1957 Miller (9) detected Zn^{65} in selected residents of Rongelap and Utirik by whole body gamma-ray spectrometry. Body burden ranged from 29.5 to 73.0 muc for the Rongelap residents, and 482 and 229 muc was detected in two subjects from Utirik. The Rongelap subjects were residing on Majuro at this time.

Miller obtained an effective half-time of 110 days for the elimination of Zn^{65}, and for the two subjects from Utirik the urinary to fecal excretion ratio was 1/9.

Assuming the excretion to be entirely exponential and 10 percent of the body burden of Zn^{65} excreted in urine, the March 1958 urinary excretion levels of 174 and 342 micromicrocuries indicate body burden, equilibrium body burden, and daily intake as follows:

	RONGELAP	
	1954 Exposed Group	Control Group (Unexposed 1954)
Body Burden (March 1958):	280 muc (± 49%)	540 muc (± 90%)
Equilibrated Body Burden:	330 muc	650 muc
Daily Intake:	2100 uuc/day #	4100 uuc/day #
Percent Equilibration:	85.0 percent	83.0 percent

The mean body burden estimated from 1958 excretion analysis for all Rongelap subjects showed a ten-fold increase over the 1957 whole body measurements. This increase correlates with the return of these people to Rongelap atoll from Majuro. Also the 1958 Rongelap Zn^{65} burdens are comparable with the Utirik subjects in 1957, and the Utirik subjects would have been in equilibrium in 1957 (half time of 110 days for the elimination of $zinc^{65}$).

The estimated intake of $zinc^{65}$ (2000 to 4000 uuc per day) can not be accounted for by Zn^{65} activity levels reported in foodstuffs. Although this radio-nuclide reportedly accounts for a large fraction of the total activity in fish, this amounts to only about six uuc per pound of muscle up to 75 uuc per pound of whole fish (2) or at most four percent of the estimated intake.

CONCLUSIONS.

Since resettlement of the Marshallese people on Rongelap atoll in July 1957, the urinary excretion level of $cesium^{137}$ has increased about 140 fold and about

Assuming 100 percent absorption from the GI Tract

20 fold for strontium^{90}. Zinc^{65} was readily detected in samples from the March 1958 medical survey.

The estimated mean body burden at equilibrium for cesium^{137} is about 1.5 microcuries or about 1/6 of the tolerance recommended by the International Commission for Radiological Protection for non-industrial populations. For strontium^{90} the mean body burden of the exposed Rongelap group in March 1958 was estimated to be two millimicrocuries. This is about nine percent of the expected equilibrium value of 23 millimicrocuries. The equilibrated strontium^{90} burden is about 1/5 of tolerance. The estimated mean body burden of zinc^{65} for Rongelap subjects in March 1958 is about 85 percent of the equilibration value of 0.6 microcuries and the equilibration value is 1/70 of tolerance.

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TABLE 1

EXCRETION LEVELS OF URINARY CESIUM^{137} AND STRONTIUM^{90}
(uuc per liter) IN THE MARSHALLESE AT VARIOUS TIMES AFTER EXPOSURE IN 1954

DATE OF COLLECTION	AGE GROUPS										MEAN ±S.D.	
	< 5 yrs		5-16 yrs		16-24 yrs		24-40 yrs		> 40 yrs			
	Cs^{137}	Sr^{90}	Cs^{137}	Sr^{90}	Cs^{137}	Sr^{90}	Cs^{137}	Sr^{90}	Cs^{137}	Sr^{90}	Cs^{137}	Sr^{90}
24 March 1954	-	-	889	11.0	294	5.4	372	3.9	258	-	405±218	7.1±2.4
25 March 1954	-	-	-	-	-	-	268	7.7	352	7.7		
17 April 1954	794	16.4	780	-	431	1.7	311	1.2	323	2.3	528±214	5.4±6.5
14 or 31 May 1954	-	-	255	13.4	427	4.2	434	0.9	543	5.5	415±100	6.0±4.6
6 or 7 Sep 1954	-	-	118	2.0	281	1.9	86	0.5	141	0.5	157±73	1.2±0.6

TABLE 2

EXCRETION LEVELS OF URINARY CESIUM^{137} AND STRONTIUM^{90}
IN THE MARSHALLESE DURING MARCH 1957

SOURCE	MEAN SAMPLE VOLUME	ACTIVITY (uuc/liter)	
		CESIUM^{137}	STRONTIUM^{90}
Exposed - Rongelap	4,100 ml	34.	0.2
Controls - Rongelap	3,664 ml	8.	< 0.2
Exposed - Utirik	2,875 ml	1535.	0.2
	TOTAL SAMPLE VOLUME		
BILLIET #9	5,400 ml	62.	0.5
IROJI #26	10,200 ml	168.	0.6
JOHN #40	2,700 ml	128.	-
TIMA #79	5,400 ml	103.	< 0.2
TOTAK #82	8,800 ml	120.	< 0.2
ALEK #2123	2,700 ml	3,759.	-
LEBAN #2125	5,400 ml	1,698	< 0.2

TABLE 3

EXCRETION LEVELS OF URINARY CESIUM^{137}, POTASSIUM^{40}, ZINC^{65}, and STRONTIUM^{90} DURING MARCH 1958

1954-EXPOSED GROUP
RONGELAP

SUBJECT	CASE NO	SEX	AGE (1958)	URINE VOL. (ml)	ACTIVITY CESIUM^{137} uuc/l	POTASSIUM^{40} gm K/l	Cs/K uuc/gm	ZINC^{65} uuc/l	STRONTIUM^{90} uuc/l
BELLA	7	M	41	2680	2181	1.0	2203	162	1.6
BILLIET	9	M	27	5700	1233	0.7	1665	100	3.8
ALMIRA	12	F	23	6745	2924	1.3	2232	264	1.5
ETRI	22	F	21	5525	5917	2.5	2357	345	6.0
IROJI	26	M	16	5915	4330	1.6	2706	223	2.1
JANWOR	31	M	36	2580	3393	2.3	1488	238	1.2
JIMAKO	39	F	19	130	13130	--	--	155	NDA
JOHN	40	M	34	1740	2275	0.9	2615	148	6.1
JOJIA	41	M	48	2690	2245	--	--	107	5.3
MONNA	66	F	34	2665	2413	1.4	1664	22	3.1
NIKTIMOS	73	M	22	4125	5584	--	--	147	5.7
NORIO	76	M	13	2665	11708	0.3	45031	237	2.8
TIMA	79	M	49	1015	3717	2.1	1796	121	2.0

TABLE 4

EXCRETION LEVELS OF URINARY CESIUM^{137}, POTASSIUM^{40}, ZINC^{65}, and STRONTIUM^{90} DURING MARCH 1958

CONTROL GROUP
(UNEXPOSED-1954)
RONGELAP

SUBJECT	CASE NO.	SEX	AGE (1958)	URINE VOL.	CESIUM^{137}	POTASSIUM^{40}	Cs/K	ZINC^{65}	STRONTIUM^{90}
				(ml)	uuc/l	gm K/l	uuc/gm	uuc/l	uuc/l
TOLMIA	818	M	7	1880	7674	0.3	24755	99.	6.4
REKO	825	F	16	400	9928	2.8	3546	337.	10.2
KEJAI	830	M	20	4275	5165	1.9	2662	553.	6.7
LOLE	831	M	18	1430	7342	1.4	5063	306	2.7
BWIO	836	M	24	585	7028	3.8	1835	88.	2.5
SAMSEN	838	M	26	10515	1867	1.1	1652	324.	3.5
ARTICLE	840	M	31	2355	3393	1.4	2458	1262.	4.1
LATA	843	F	33	6490	2068	0.7	3041	75.	1.7
NAMON	849	M	39	2640	3880	3.3	1158	948.	5.0
MONEAN	855	M	60	2655	3176	1.2	2669	120.	2.5
JONNI	865	F	25	2125	4624	1.7	2688	319.	4.1
BATOL	872	M	14	5275	7736	1.9	3947	195.	1.3
ANTY	874	M	10	4650	6141	0.9	6533	131.	3.2
HANAKO	876	F	20	2155	2909	0.3	9091	163.	3.3
ATARIK	877	M	20	5245	3311	1.5	2164	233.	2.0
JEKOB	883	M	46	2615	3386	2.1	1628	271.	2.7
KETO	887	M	13	2630	11733	2.2	5357	398	4.7

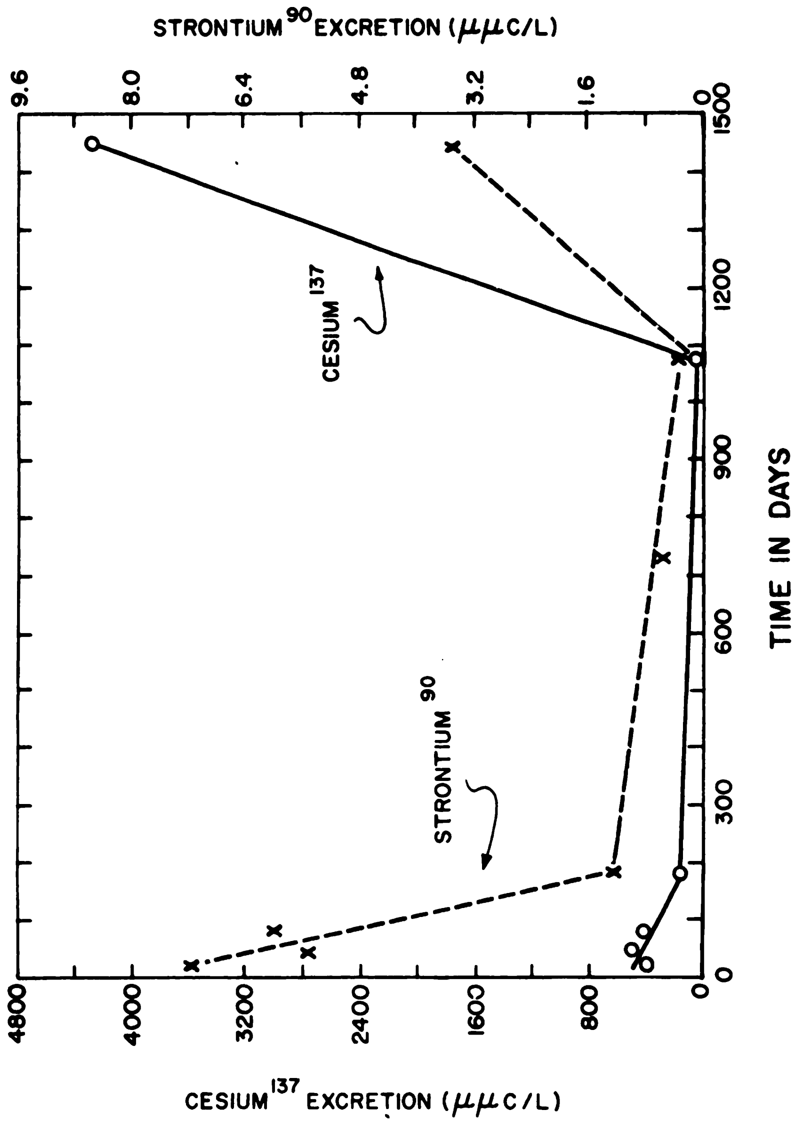


Figure 1. Excretion Levels of Urinary Cesium^{137} at Various Times After Exposure

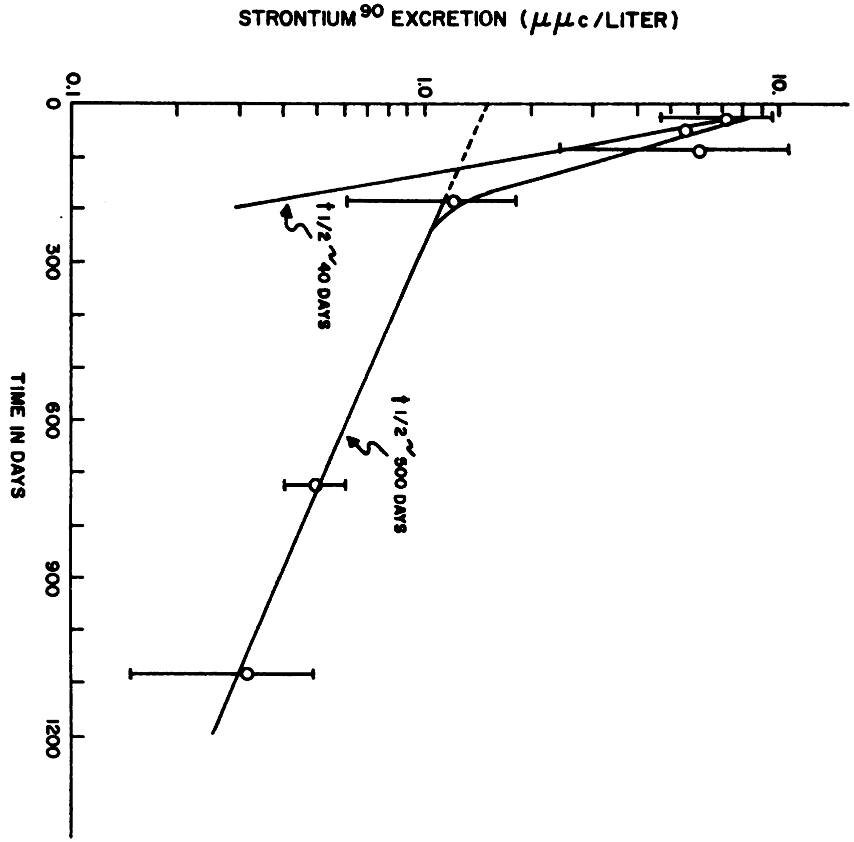


Figure 2. Excretion Levels of Urinary Strontium^{90} at Various Times After Exposure

APPENDIX

I. In the case of strontium elimination, the following assumptions were made:

a. The population was returned to the contaminated atoll at time $t = o$, with a zero strontium body burden.

b. The population absorbs a daily increment of x uc, and x is considered to be a constant independent of time.

c. The amount of strontium excreted in the urine each day is given by $P(t) = \frac{1}{k}E(t)$, where $E(t)$ is the total excreted by all routes each day, and k is a constant independent of time.

d. The body is considered to be a two compartment system, A and B, where $A + B = 1$. The excretion rates for each compartment are a and b days^{-1} respectively. The portion of $E(t)$ excreted from each compartment is proportional to the burden remaining in that compartment. For cesium and zinc elimination similar assumptions are made, except that only one compartment is assumed.

e. Now:

$s(t)$ is total strontium body burden at time t in uc

$s_1(t)$ and $s_2(t)$ are the portions in each compartment

and $s(t) = s_1(t) + s_2(t)$

Considering each compartment seperately and adding the results,

$$\frac{ds}{dt^1} = Ax - E_1(t) = Ax - k\,P_1(t) = Ax - as,$$

hence $s_1(t) = \frac{Ax}{a}(1 - e^{-at})$ and $s_2(t) = \frac{Bx}{b}(1 - e^{-bt})$

Since $E(t) = as_1 + Bs_2$

$$P(t) = \frac{1}{k}(as_1 + bs_2)$$

equilibrium body burden $M = \lim_{t \to \infty} s(t)$

$$s(t) = x\left[\frac{A}{a}(1 - e^{-at}) + \frac{B}{b}(1 - e^{-bt})\right]$$

$$M = x\left(\frac{A}{a} + \frac{B}{b}\right)$$

$$P(t) = \frac{x}{k}\left[A(1 - e^{-at}) + B(1 - e^{-bt})\right] = \frac{x}{k}(1 - Ae^{-at} - Be^{-bt})$$

1. $y = \%$ of equilibrium $= \dfrac{s(t)}{M} = \dfrac{\frac{A}{a}(1 - e^{-at}) + \frac{B}{b}(1 - e^{-bt})}{\frac{A}{a} + \frac{B}{b}}$

2. $s(t) = kP(t)\,\dfrac{\frac{A}{a}(1 - e^{-at}) + \frac{B}{b}(1 - e^{-bt})}{A(1 - e^{-at}) + B(1 - e^{-bt})}$

3. $x = \dfrac{kP(t)}{A(1 - e^{-at}) + B(1 - e^{-bt})}$

4. $M = kP(t)\,\dfrac{\frac{A}{a} + \frac{B}{b}}{A(1 - e^{-at}) + B(1 - e^{-bt})}$

f. The following values for strontium metabolism were obtained from Supplement No. 6 of the British Journal of Radiology:

$A = \frac{7}{12}$ $\quad B = \frac{5}{12}$ $\quad k = 1$ $\quad$ and $\quad s_o = o$

$a = 3.65 \times 10^{-3}$ days^{-1} and $b = 1.73 \times 10^{-4}$ days^{-1}, corresponding to a half-time of elimination of 190 and 4000 days respectively.

$x = 0.6\,x'$ and x' is total daily intake.

At t = 270 days:

$P(t) = 3.45 \times 10^{-6}$ uc/day (1954 Exposed Rongelap Subjects)

3.9×10^{-6} uc/day (control Rongelap Subjects - Unexposed 1954)

II. In the case of cesium and zinc:

$$s(t) = \frac{x}{a}(1 - e^{-at}) + s_o e^{-at}$$

x is the daily accretion in uc/day, and s_o is the body burden in uc at $t = o$.

$$\frac{ds}{dt} = -as + x = -a\left[s_o e^{-at} + \frac{x}{a}(1 - e^{-at})\right] + x$$

$$= -E(t) + x$$

$$kP(t) = E(t) = a\left[s_o e^{-at} + \frac{x}{a}(1 - e^{-at})\right]$$

$$M = \lim_{t \to \infty} s(t) = \frac{x}{a}$$

Zinc[65]

$a = 6.3 \times 10^{-3}$ days^{-1} ($t1/2 = 110$ days) $k = 10$

$s_o = 0.03$ uc

Cesium[137]

$a = 4.6 \times 10^{-3}$ days^{-1} ($t1/2 = 150$ days) $k = 1$#

$s_o = o$

#The urinary/fecal ratio of radiocesium for human subjects is about 5/1, so that estimates of body burden are too low by about 20 percent.

HUMAN COUNTING FACILITY

AT THE
WALTER REED ARMY INSTITUTE OF RESEARCH

WALTER REAM ARMY MEDICAL CENTER

WASHINGTON, D. C.

Supported jointly by Funds from the

ARMED FORCES SPECIAL WEAPONS PROJECT

AND THE

OFFICE OF THE SURGEN GENERAL OF THE ARMY

Kent T. Woodward, Major MC

Harry A. Claypool, Captain MC

James B. Hartgering, Lt. Colonel, MC

The Whole Body Counter at the Walter Reed Army Institute of Research became fully operational on 14 July 1958. During the period 14 July 1958 through 31 March 1959, a total of 1278 persons was measured for levels of Cesium-137 and Potassium-40. Of these, 797 were selected from the total persons studied, by the criteria of having no history of possible radioactive contamination through occupation, and being physically normal, without history of significant disease.

The data has been prepared utilizing the quotient of the two measurements as the most reliable normalization of the results. Since Cesium has the same valence as Potassium, and presumably the same whole body distribution in man, the ratio of these two measurements expressed as micro-microcuries of Cesium-137 per gram of natural potassium, eliminates weight as a variable, and makes it possible to compare levels in people regardless of their total weight, muscle mass, age and sex.

Cesium-137 taken by human volunteers gave a half-times for excretion of 150[1] days. On the basis of this value, the residence for an individual is taken to be that area in which he has most recently resided for a period of at least six months. In other words, it is assumed that if geographical location has an effect on total body burden of Cesium-137, a person must live for at least six months in an area before their body burden would reflect the local levels.

The Walter Reed Facility (Fiqure 1) was designed to count large numbers of people, since the normal biological variation in levels of this isotope is of the order of 30%. Statistical studies on 425 individuals measured from July to December of 1958 showed a mean age of 31 years (σ=32%) and a mean weight of 159 pounds (σ=18%). The population studied is weighted toward younger people because of our large military component. (Figures 1 and 2)

Detailed results of the data are presented in Figures 2 through 9. Figure 4 shows the variation in radioactivity in the population measured due to the inherent

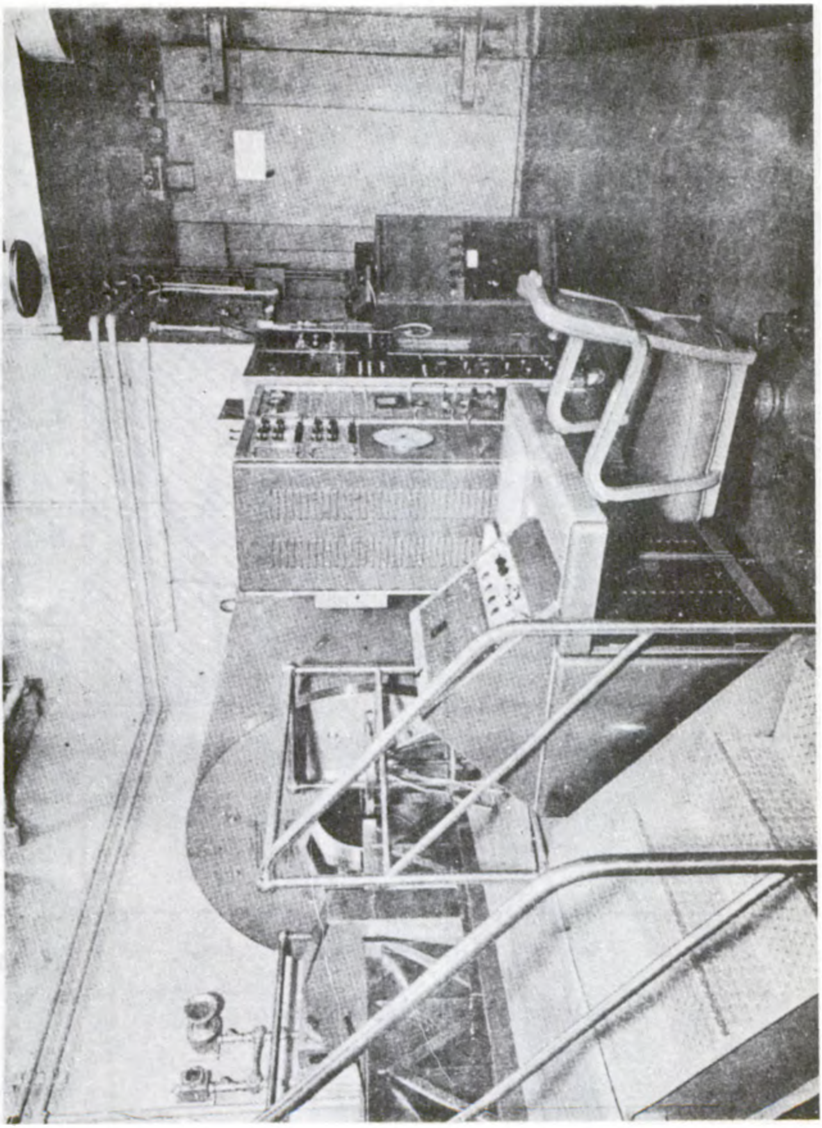


Figure 1

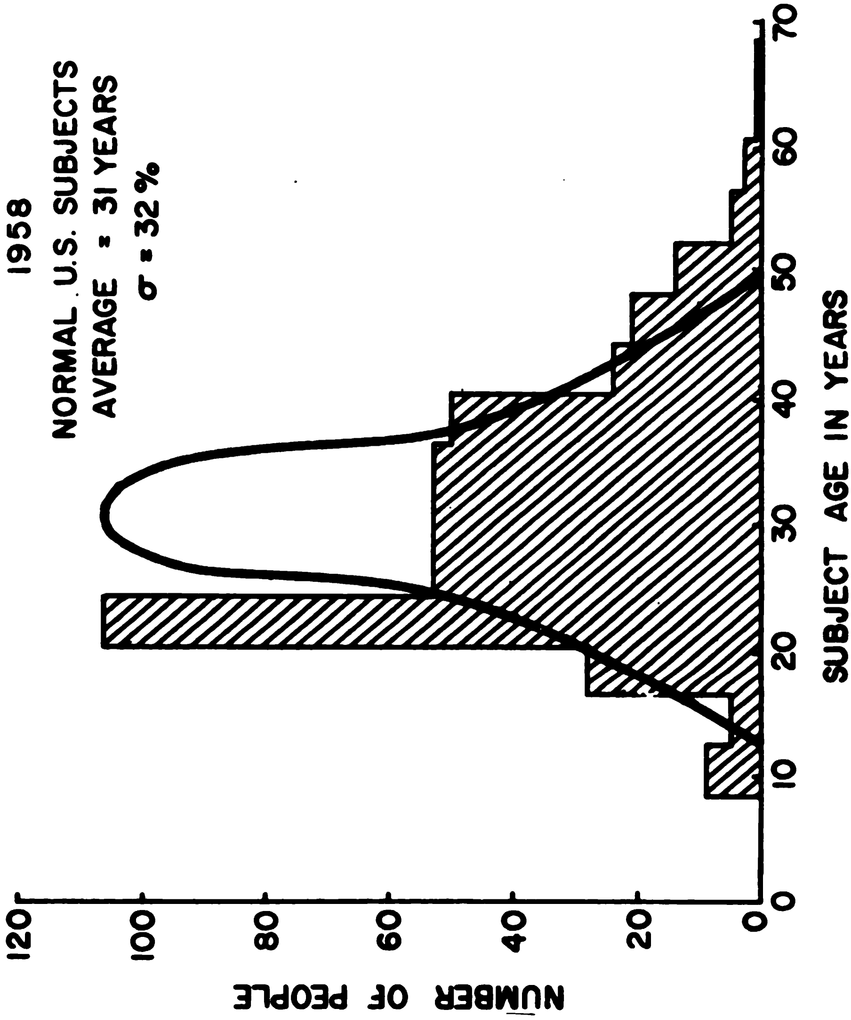

1958
NORMAL U.S. SUBJECTS
AVERAGE = 31 YEARS
σ = 32%
SUBJECT AGE IN YEARS
0
10
20
30
40
50
60
70
NUMBER OF PEOPLE
0
20
40
60
80
100
120

Figure 2

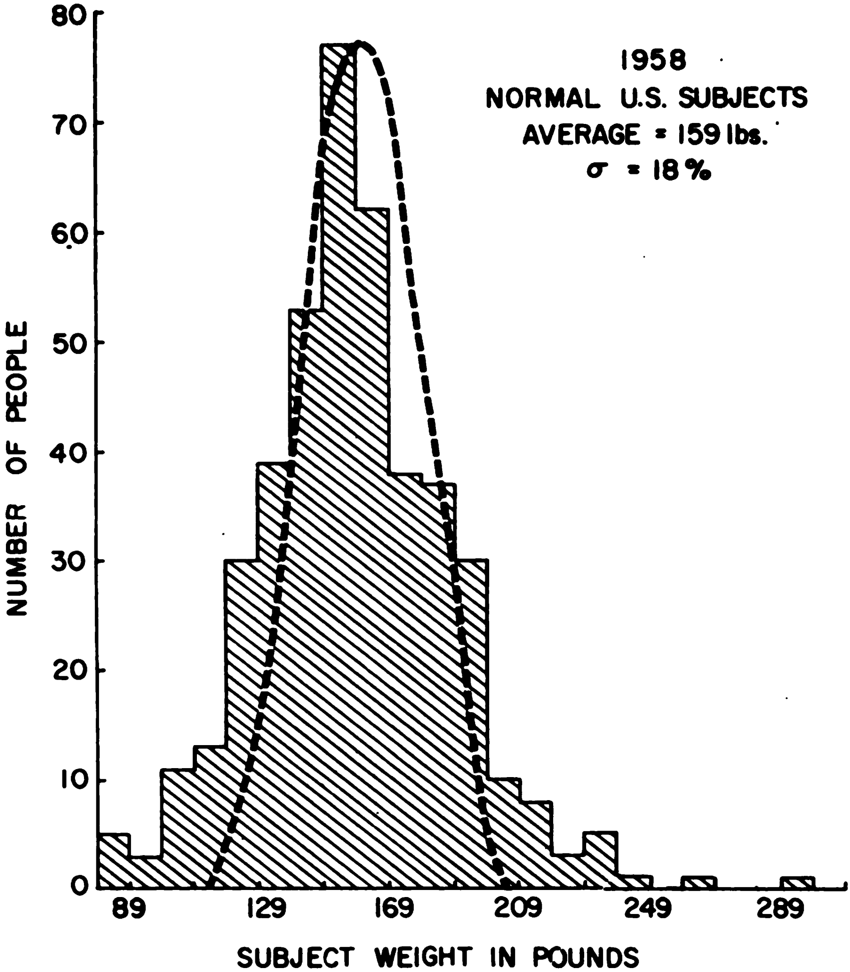

1958
NORMAL U.S. SUBJECTS
AVERAGE = 159 lbs.
σ = 18 %
NUMBER OF PEOPLE
80
70
60
50
40
30
20
10
0
89
129
169
209
249
289
SUBJECT WEIGHT IN POUNDS

Figure 3

potassium-40. The mean was 2.45 disintegrations per second per pound of total body weight (σ = 14%). This result is 6% lower than the value of 2.60 obtained by Dr. E. Anderson and the Los Alamos group.

Figure 5 shows the distribution of the results for Cesium-137 activity. A mean of 1.66 dps per pound (σ = 30%) was obtained. Figure 6 shows the spread of results obtained for potassium-40 activity versus total body weight.

A group of ten Reed College students provided an excellent opportunity for comparison of the results from the Los Alamos and Walter Reed Facilities. This group was measured 25 February 1959 at Los Alamos and was again counted on 2-3 April 1959 at Walter Reed. The results of this study are presented in Table 1. The agreement is considered excellent, particularly in view of the fact that two entirely independent methods of calibration were used. The somewhat lower value for potassium-40 activity obtained at Walter Reed is believed to be caused by the somewhat better geometry presented to the counter by our standards than is the case for a human being. New standards are being prepared which will more closely approximate the geometry of a man. This should result in a steeper slope to the mass versus efficiency curve, with a lower efficiency at higher total body weights and a resulting higher value for the calculated activity due to potassium-40. The lower value for potassium activity also directly explains the slightly higher value obtained for uuc Cs^{137} per gram of potassium.

Table 2 summarizes the data on 656 residents of the U.S. measured between July 1958 and March 1959, and Table 3 in like manner presents the results obtained on residents of Foreign countries. Most of the so-called Foreign residents actually represent U.S. troops returned from overseas tours of duty in excess of six months.

Tables 4,5 and 6 present a detailed geographical breakdown of all the data. Figures 7,8 and 9 present the results from the United States for the time periods

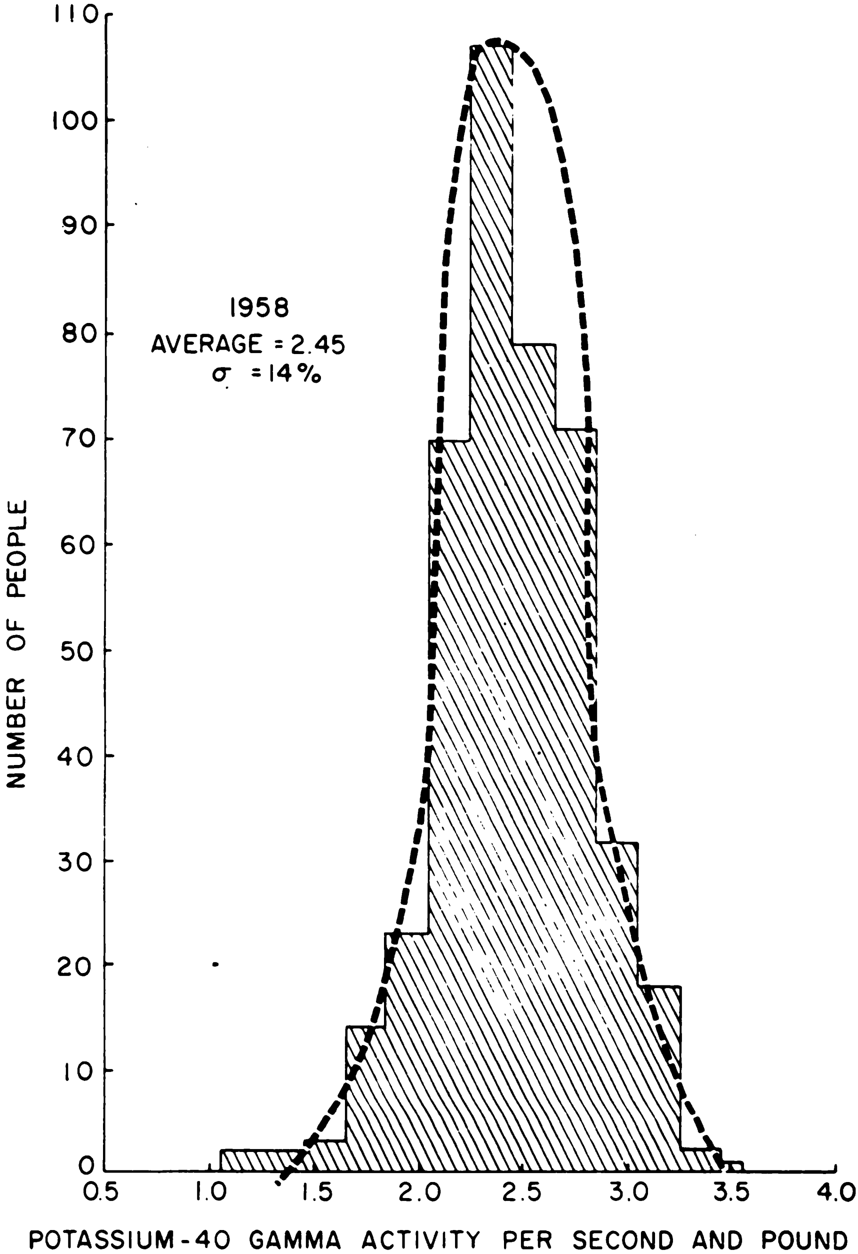

110
100
90
80
70
60
50
40
30
20
10
0
NUMBER OF PEOPLE
1958
AVERAGE = 2.45
σ = 14%
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
POTASSIUM-40 GAMMA ACTIVITY PER SECOND AND POUND

Figure 4

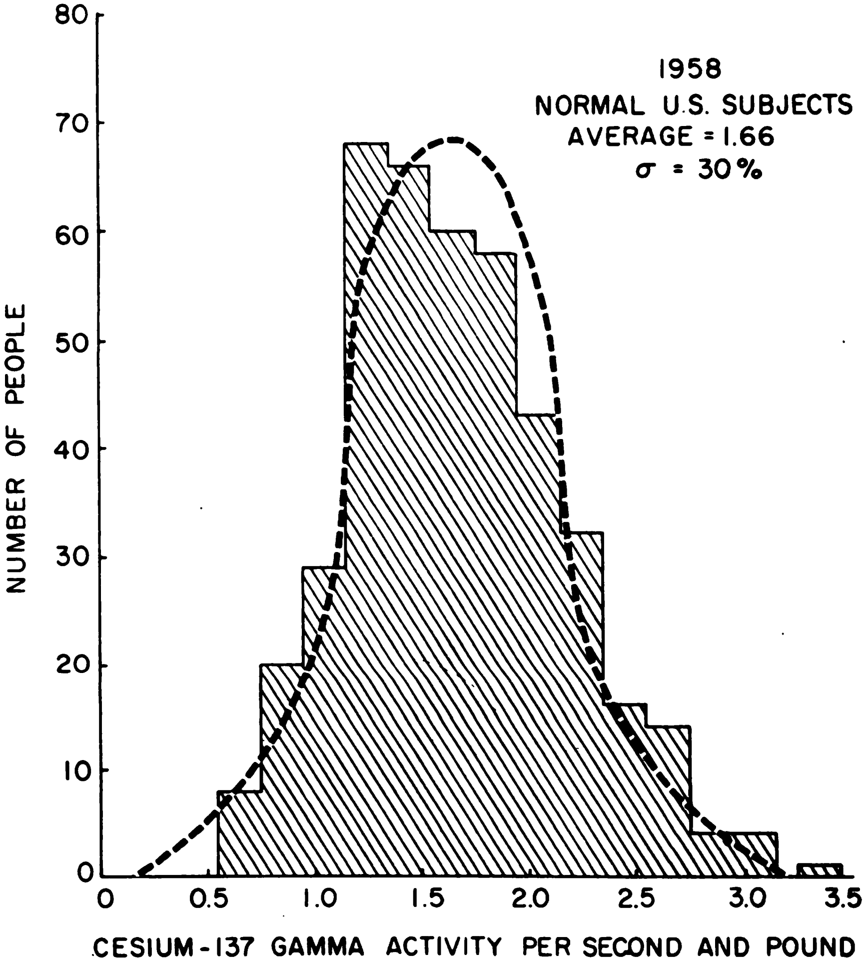

1958
NORMAL U.S. SUBJECTS
AVERAGE = 1.66
σ = 30%
NUMBER OF PEOPLE
80
70
60
50
40
30
20
10
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
CESIUM-137 GAMMA ACTIVITY PER SECOND AND POUND

Figure 5

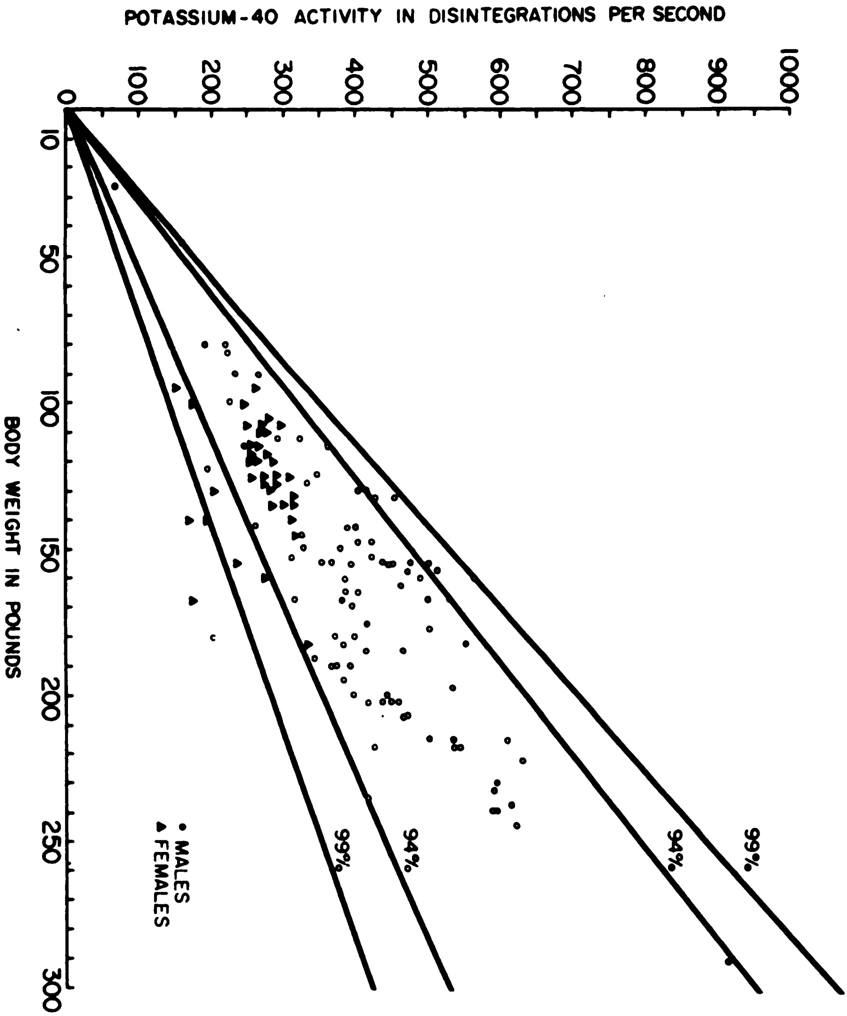

POTASSIUM-40 ACTIVITY IN DISINTEGRATIONS PER SECOND
0
100
200
300
400
500
600
700
800
900
1000
BODY WEIGHT IN POUNDS
10
50
100
150
200
250
300
99%
94%
94%
99%
• MALES
▲ FEMALES

Figure 6

Table 1. Cs-137 and K-40 Levels in Ten Individuals Measured at Los Alamos Scientific Laboratory (25 Feb. 1959) and Walter Reed Army Institute of Research (2-3 April 1959).

	Mean			Standard Deviation	
Parameter	Los Alamos	Walter Reed	% Diff.	Los Alamos	Walter Reed
DPS Cs^{137}/lb.	1.77	1.75	1.1	0.29	0.26
DPS K^{40}/lb.	2.84	2.62	7.8	0.24	0.19
uuc Cs^{137}/gram K	63	67	6.4	10	9

Table 2. Cesium-137 Levels in Man - United States - July 1958 - March 1959.

Area	Cesium-137 Levels 1958 July-Dec.	Cesium-137 Levels 1959 Jan.-March	Cesium-137 Levels Average July-March	Number Persons Measured 1958 July-Dec.	Number Persons Measured 1959 Jan.-March	Number Persons Measured Total July-March
Northeast	69	69	69	375	118	493
Southeast	70	85	74	14	4	18
N. Central	75	67	71	23	19	42
S. Central	76	57	70	30	15	45
Northwest	65	78	71	7	6	13
Southwest	63	55	60	25	20	45
Washington, D.C.	67	69	67	320	100	420
Total U.S.	69	67	68	474	182	656

Cesium-137 Levels in uuc Cs^{137}/gram K

Table 3.

Area	Cesium-137 Levels			Number Persons Measured		
	1958 July-Dec.	1959 Jan.-March	Average July-March	1958 July-Dec.	1959 Jan.-March	Total July-March
United States	69	67	68	474	182	656
Europe	78.5	77	78	47	18	65
Middle East	60	71	66	2	3	5
Far East	69	58	64	26	23	49
Central America	72	56	62	2	3	5
South America	40	64	44	6	1	7
Other	70	65	67	4	6	10
All Non U.S.	72	66	70	87	54	141
Total World	70	67	68.5	561	236	797

Table 4. Micro-Micro Curies Cs^{137}/gram K over the U.S. July 1958 through March 1959

	μμc Cs^{137}/gram potassium			Number Surveyed		
Area	14 July '58 to 12 Dec. '58	12 Dec. '58 to 31 March '59	Cumulative Average	14 July '58 to 12 Dec. '58	12 Dec. '58 to 31 March '59	Total
Northeast	69	69	69	375	118	493
Area 1	70	53	68	7	1	8
2	79	69	75	8	5	13
7	80	69	77	40	12	52
8	67	69	67	320	100	420
Southeast	70	85	74	14	4	18
Area 13	70	104	73	11	1	12
18	72	79	76	3	3	6
N. Central	75	67	71	23	19	42
Area 3	58	69	65	3	6	9
4	67	-	67	2	0	2
9	78	67	74	15	10	25
10	80	63	72	3	3	6
S. Central	76	57	70	30	15	45
Area 14	79	71	78	17	3	20
15	89	48	71	5	4	9
19	81	62	67	1	3	4
20	60	52	57	7	5	12
Northwest	65	78	71	7	6	13
Area 5	42	-	42	2	0	2
6	74	78	76	5	6	11
Southwest	63	55	60	25	20	45
Area 11	72	66	70	7	4	11
Area 12	62	57	60	6	5	11
16	62	50	55	3	4	7
17	58	51	55	9	7	16

Table 5. Micro-Micro Curies Cs^{137}/gram K in Man - World Wide - July 1958 through March 1959

Area	uuc Cs^{137}/gram potassium: 14 July '58 to 12 Dec. '58	12 Dec. '58 to 31 March '59	Cumulative Average	Number Surveyed: 14 July '58 to 12 Dec. '58	12 Dec. '58 to 31 March '59	Total
U.S. Area 1	70	53	68	7	1	8
2	79	69	75	8	5	13
3	58	69	65	3	6	9
4	67	-	67	2	0	2
5	42	-	42	2	0	2
6	74	78	76	5	6	11
7	80	69	77	40	12	52
8	67	69	67	320	100	420
9	78	67	74	15	10	25
10	80	63	72	3	3	6
11	72	66	70	7	4	11
12	62	57	60	6	5	11
13	70	104	73	11	1	12
14	79	71	78	17	3	20
15	89	48	71	5	4	9
16	62	50	55	3	4	7
17	58	51	55	9	7	16
18	72	79	76	3	3	6
19	81	62	67	1	3	4
20	60	52	57	7	5	12
Area 8	67	69	67	320	100	420
All other U.S.	74	64	70	154	82	236
Total U.S.	69	67	68	474	182	656
All Non U.S.	72	66	70	87	54	141
Total World	70	67	68.5	561	236	797

Table 6. Micro-Micro Curies Cs^{137}/gram K in Man - World Wide - July 1958 through March 1959.

Area	uuc Cs^{137}/gram potassium			Number Surveyed		
	14 July '58 to 12 Dec. '58	12 Dec. '58 to 31 March '59	Cumulative Average	14 July '58 to 12 Dec. '58	12 Dec. '58 to 31 March '59	Total
Europe	78.5	77	78	47	18	65
Italy	107	53	89	2	1	3
France	86	109	89	15	2	17
Germany	72	74	73	28	15	43
England	99	-	99	1	-	1
Holland	74	-	74	1	-	1
Middle East	60	71	66	2	3	5
Turkey	82	54	68	1	1	2
Iran	38	-	38	1	-	1
Pakistan	-	79	79	-	2	2
Far East	69	58	64	26	23	49
Hawaii	65	71	66	6	2	8
Guam	52	-	52	2	-	2
Philippines	82	51	66	1	1	2
Japan	72	60	69	15	6	21
Korea	72	55	58	2	11	13
Thailand	-	46	46	-	1	1
Formosa	-	67	67	-	1	1
Okinawa	-	58	58	-	1	1
Central America	72	56	62	2	3	5
Panama	78	-	78	1	-	1
Puerto Rico	63	62	62	1	1	2
Cuba	-	57	57	-	1	1

Table 6. — Continued

Area	μμc Cs^{137}/gram potassium 14 July '58 to 12 Dec. '58	12 Dec. '58 to 31 March '59	Cumulative Average	Number Surveyed 14 July '58 to 12 Dec. '58	12 Dec. '58 to 31 March '59	Total
Central America continued						
Guatemala	-	50	50	-	1	1
South America	40	64	44	6	1	7
Colombia	116	-	116	1	-	1
Venezuela	67	64	66	1	1	2
Brazil	15	-	15	4	-	4
Other	70	65	67	4	6	10
Alaska	69	51	64	3	1	4
Australia	75	-	75	1	-	1
Canada	-	73	73	-	2	2
Midway	-	53	53	-	1	1
Newfoundland	-	70	70	-	2	2

indicated, plotted in the arbitrarily chosen geographical subdivisions.

The most impressive thing about this large collection of data on human beings is the effect of the normal biological variation on results obtained from small groups of people. With a few exceptions, any analysis accomplished by increasing the size of the group, whether by combining small geographical areas into larger ones, or by increasing the period of time over which the average is taken, results in the mean level for Cs^{137} activity in the group approaching that determined for the largest group studied, namely, the Washington, D.C. area.

Considering the normal distribution of the results (Figure 5) it is apparent that if two areas are to be compared, large numbers of individuals must have been measured from each of the two areas. The only two U.S. areas satisfying this criterian are areas 7 and 8, in which 52 and 420 individuals were counted respectively. The levels of 77 and 67 uuc Cs^{137} per gram of potassium suggest that perhaps a real difference exists between these two areas. However, since the areas are contiguous, the reason for the difference is not readily apparent. The possibility of a significant difference in rainfall must be considered, since the great majority of people measured in Area 8 are from the immediate Washington, D.C. area.

Comparing larger geographical subdivisions shows little difference in the results except perhaps for the southwestern part of the nation. Dr. Anderson's results should clarify this question, since most of his subjects should be from this area.

The World Wide results also follow this pattern, with two exceptions. Levels in troops returned from Europe appear higher than those obtained for the resident U.S. population. Results on seven cases from South America indicate a significantly lower level for the southern hemisphere than for the northern hemisphere. However, considerably larger numbers of people from these areas should be counted to confirm this impression. A similar result was obtained by Marinelli et al on 23 May 1957 on

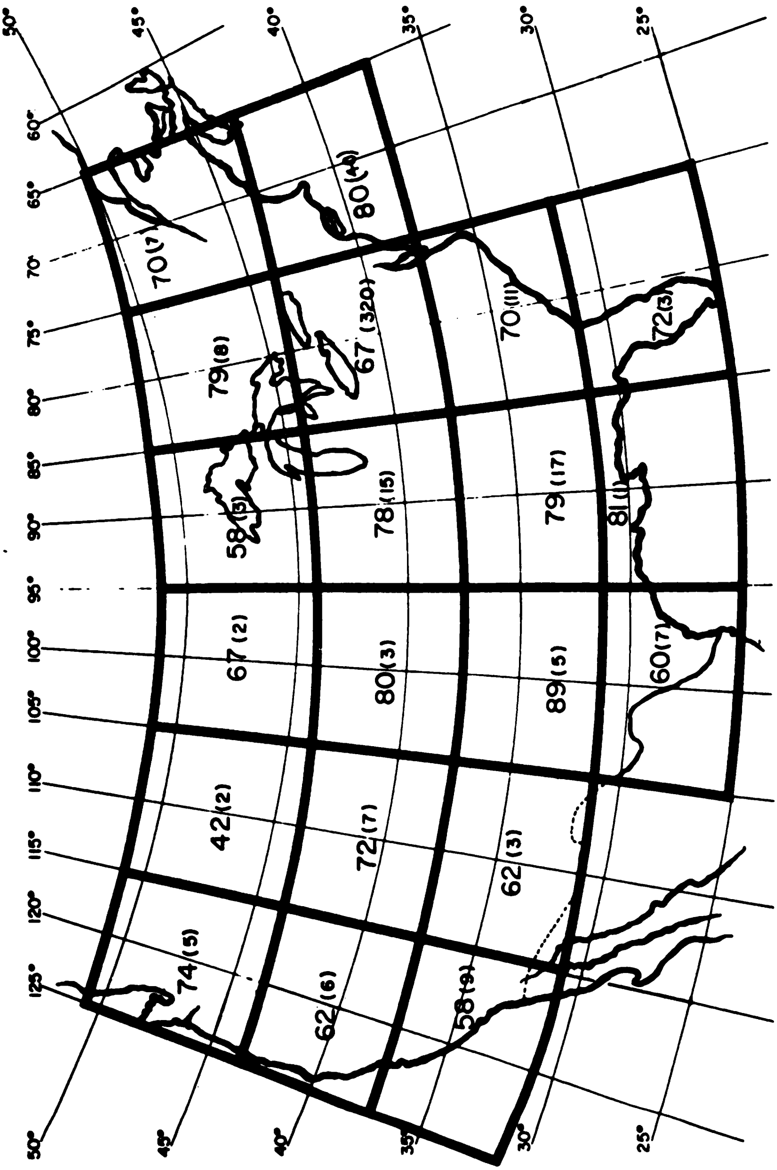
11 South American subjects who showed a mean of 14.6 uuc Cs^{137}/gram K as opposed to a mean of 35 for Chicago subjects at this same time.[2]

Figures 7,8 and 9 show the results for the three time periods indicated plotted on a U.S. Map in twenty arbitrary geographical subdivisions. Because of the small numbers of individuals measured from many of these areas, it is not possible to draw conclusions regarding variation in levels over the nation. For the same reason, over the short period of nine months of operation, no conclusion has been attempted regarding possible increase or decrease in the average national level over the past nine months.

Figure 10 is a composite curve obtained from the data of Anderson[3] and Marinelli[2], plotted from March of 1955 to the present.

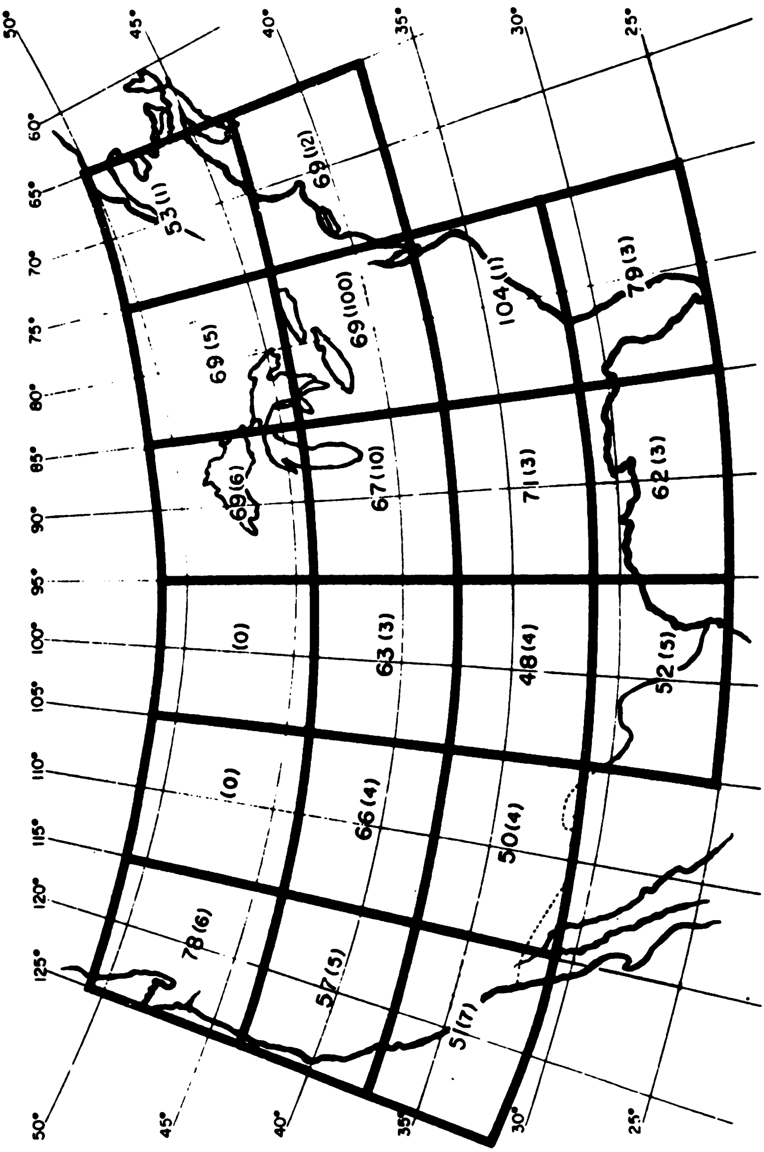
The curve from Marinelli's data was obtained by calculating means from the curves for his 8 control subjects. Anderson's data was then plotted to the same scale, as were the two points representing the data from Walter Reed Army Institute of Research.

It is hoped that the Facility at the Walter Reed Army Institute of Research will provide data from large numbers of people. In conjunction with the Whole Body Counter to be placed in operation in June of 1959 at Landstuhl, Germany by the U.S. Army, considerably more data will be obtained in the next few years. Only a long range program will permit detailed analysis of the variables pertinent to this problem.



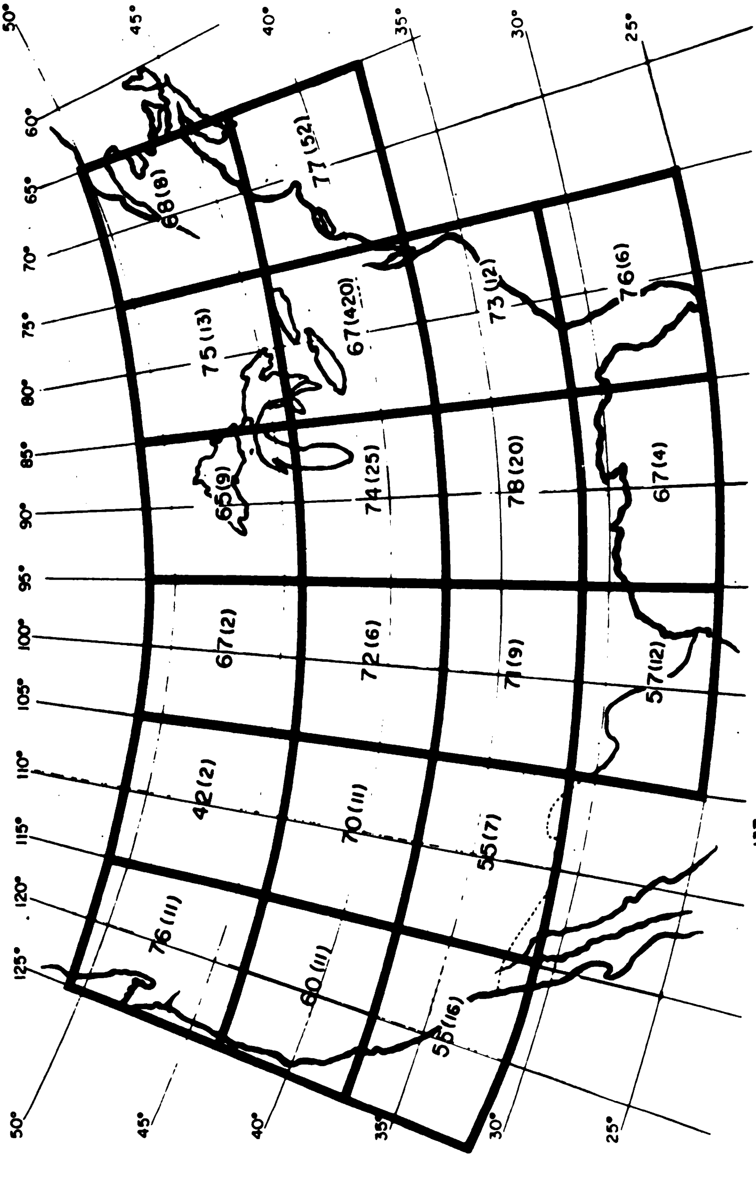
CESIUM 137 LEVELS ($\mu\mu c$/qmK) IN NORMAL U.S. SUBJECTS DURING 1958.

Figure 7



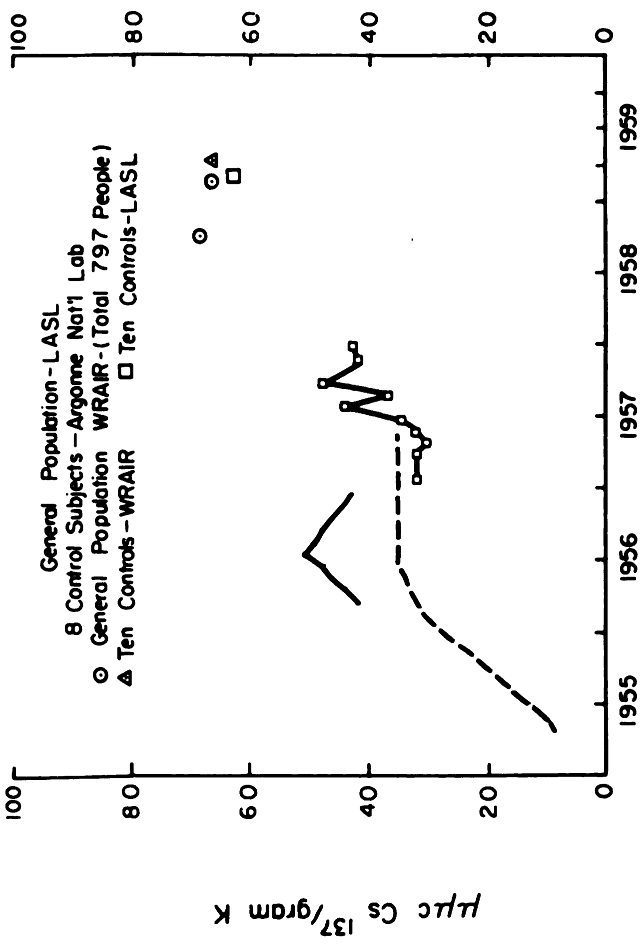
CESIUM [137] LEVELS ($\mu\mu c$/qmK-) IN NORMAL
U.S. SUBJECTS 12 DEC. 58 - 31 MARCH 1959
TOTAL 182 INDIVIDUALS

Figure 8



CESIUM [137] LEVELS ($\mu\mu c/gmK$) IN NORMAL
U.S. SUBJECTS JULY 1958 - MARCH 1959
(TOTAL 797 INDIVIDUALS)

Figure 9



COMPOSITE DATA-CESIUM-137 LEVELS IN UNITED STATES POPULATION

Figure 10

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(3) Anderson, E.C., "Radioactivity of People and Milk", 1957, Science, Oct. 17, 1958, Vol. 128 No. 3329, pp 882-886

Colonel HARTGERING. Thank you, sir.

In view of the question of the last speaker, I will change the order of my summary slightly and present the Marshallese data first. This is the first result of a 5-year study by myself and my colleagues at Walter Reed in conjunction with the Atomic Energy Commission and it represents an attempt to look at the long-range excretion and retention problems associated with the acute 2-day internal exposure these individuals sustained in 1954.

May we have the first slide, please. This slide (on file with Joint Committee) represents the cesium levels over a period of 180 days, and it indicates a half-time excretion in this population of some 200 people of the order of 110 days. This agrees well with the human volunteer studies in this country which give a half excretion time of about 150 days. This means, sir, that as the isotope is handled in the body, half of it is turned over and excreted primarily in the urine, about every 110 days. The physical half-life of the isotope is of the order of 30 years. The one thing that this slide does not show, but is in my prepared material, is the result of the resettlement of the Marshallese in 1957. In 1957, you will recall, they were returned to their home island. One year later our study showed an increase in cesium levels internally by a factor of about 100. This is an example of what happens even though people are away for many years from an island that has been exposed to relatively heavy fallout. The material is still there. It gets into their food. They ingest it and it gets into their bodies.

Representative HOLIFIELD. In other words, after you moved them back after they were away 100 days——

Colonel HARTGERING. They had been away 3 years.

Representative HOLIFIELD. The level started rising.

Colonel HARTGERING. The level in the body started rising again and is now about 50 percent greater than it was in 1954. It has leveled off and it is my understanding that the 1959 study shows that this is about where it will stay. May we have the next slide, please.

This is another isotope, strontium, and it shows the excretion rates over a period of several years. It shows that at early times there is a rapid excretion with a half turnover time in the body of about 40 days but then a fraction which goes to bone and is turned over relatively slowly, a half turnover time of something around 500 days.

Strontium, too, when they were returned to their island, was increased, but not as great as the cesium. Maybe about a twentyfold increase over what it was in 1957.

Representative HOSMER. Can you estimate the body burden?

Colonel HARTGERING. These body burdens are running something of the order of perhaps 2 millimicrocuries now. In the United States we are at about 5 micromicrocuries.

Representative HOSMER. Is it estimated back from there or do you have to obtain the information otherwise?

Colonel HARTGERING. We can estimate the information from excretion curves like this provided we know when the exposure occurred. In this case we knew exactly when the exposure was.

Representative HOLIFIELD. In applying this to populations that would be exposed, such as this attack pattern assumes, it would be pertinent to observe there would be a continuing hazard of buildup even years after the attack.

Colonel HARTGERING. That is right, sir. There is a continuing exposure problem.

Representative HOLIFIELD. Have you done any figuring on the amount of buildup that would occur as a result of an attack of this kind, or is that possible?

Colonel HARTGERING. We have tried to do this sir. It is a very difficult problem to handle. The difficulties arise for these reasons: First of all, you have predicated all surface bursts. As we heard earlier in the testimony, fractionation, that is, the degree that goes up in the atmosphere, is different for surface bursts than it for air bursts. The fractionation for individual isotopes such as strontium and cesium may be different. Also the body burdens that we are now measuring in man, you and me and everyone, is the result of testing over a period of years. The acute exposure predicated here would give an entirely different picture. So it is pretty tenuous extrapolation to move from the data we now have to the condition here. All one can do is estimate. I don't know any real good way of doing this, except that we know you can multiply the number of fission megatons used in this attack by the ones already fired. This in my estimation would give a figure that is low by at least 50 percent or more, because of the long delay time in existing programs and the acute nature of the postulated attack.

Representative HOLIFIELD. We know these Marshall Island people were removed after 2 days of exposure.

Colonel HARTGERING. Yes, sir.

Representative HOLIFIELD. They stayed away 3 years and then they came back to their island.

Colonel HARTGERING. Yes.

Representative HOLIFIELD. In the case of a continental attack on the United States or upon the European Continent, it is obvious that you could not take people away as we did the Marshallese from the island. Therefore, there will be a continuous exposure during that first 3 years which would be inevitable, I would say. You could take parts of the country that were not as intensely attacked but you would still have exposure there, I would assume.

Colonel HARTGERING. Yes, sir. There are certainly countermeasures to minimize this but you can't get rid of it completely.

Representative HOSMER. Perhaps we could get on the record at this point the comparisons. If you have them, I would like to know what the current level for the U.S. population is with regard to strontium, what it is with the Marshallese at some point that would be comparable, and what the maximum permissible dose would be.

Colonel HARTGERING. We have not gathered recent data on strontium 90. I can only quote from memory here. It is the order of five micromicrocuries certainly in the younger proportion of the population. It is about two millimicrocuries in the Marshallese. Again this is a rough estimate. It varies considerably depending on the age of the individual. This is of the order of a sixtieth of the current accepted general tolerance.

Representative HOLIFIELD. Which is it, the two or the five?

Colonel HARTGERING. The two. If there are no further questions I will turn to the worldwide problem.

This is a picture of the counter at Walter Reed (p. 567) that was designed to measure the levels of gamma activity in man directly. It is a large scintillation counter based on the principles developed by Dr. Ernest Anderson at Los Alamos, where there is also a similar counter. Within the past month the U.S. Army has put in operation a Los Alamos designed counter in Germany, to further the studies that I will summarize in the next few slides. There are now three of these in the world, which will measure the amounts of activity in people directly.

The next slide, please (on file with Joint Committee). This I show in summary because it gives an idea of the biological variation between individuals in our population. This shows that there is a one sigma variation of 30 percent. Variation is from 0.5 activity per second per pound to something of the order of three. This is the extreme biological separation that is present in all of the medicine. It is something that is normally overlooked. We are not all the same and have different amounts of isotopes in us depending upon how we individually handle the particular isotope that we are looking at.

May I have the next slide.

In spite of this when one looks at large groups of people—and we have now looked at 1,500 people since last July at Walter Reed—some very surprising things perhaps develop. The main thing I would like to point out on this slide is that if we look at the United States and divide it into the various sectors, with the exception of the southwestern part of the country the averages for cesium in man are surprisingly uniform. The southwestern part of the country, perhaps as Dr. Machta pointed out because of less rainfall, has a significantly lower level of cesium activity in the people.

However, the rest of the sections of the country are essentially the same.

May I have the next slide (on file with Joint Committee). This also carries on when we look at the world. As a result of the testing program so far, we can see that as long as we stay in the Northern Hemisphere the numbers are essentially the same. The average level from last July to March of this year in the United States is 68.

In Europe it is 70. Middle East 66. And so on down the line. When we drop to South America, although the numbers of people we have observed is indeed small there, nevertheless, these were individuals whom we saw the day after they arrived and I feel this represents what other people have stated, namely, that the levels in the Southern Hemisphere are again small. I think what this says is that in an attack such as we predicated here, as far as the worldwide fallout is concerned, people all over the northern part of the world are going to get essentially the same amount of internal radiation within their body.

Representative HOLIFIELD. You would not confine that only to the north temperate zone. It is the north and south temperate zones.

Colonel HARTGERING. It is north of the equator, sir.

Representative HOLIFIELD. North of the equator we would get most of it.

Colonel HARTGERING. We would get the most of it and the distribution is essentially uniform. People no matter where they live north of the equator would get this. South of the equator it is less.

Representative HOLIFIELD. The units you are using are one millionth of a millionth of a curie?

Colonel HARTGERING. That is right.

Representative HOLIFIELD. How does this relate to the maximum permissible dose?

Colonel HARTGERING. This is of the order of a hundredth of the maximum permissible exposure.

Representative HOLIFIELD. Which society figures are you using?

Colonel HARTGERING. The international commission recommendations for the general population.

Representative HOLIFIELD. In other words, the average person measures today about one one-hundredth.

Colonel HARTGERING. Or a little less.

Representative HOLIFIELD. Than the maximum permissible dose?

Colonel HARTGERING. That is right.

Representative HOLIFIELD. As set up by the International Commission on Radiological Protection, is that right?

Colonel HARTGERING. Yes, sir.

I could summarize by saying that utilizing equipment of this type, developed principally by the Los Alamos group, it is possible to measure activities directly in man without going through the animal extrapolation problems. The levels of strontium and indeed the several other isotopes that will be present following an attack such as you predicated could also be measured directly in people, foodstuffs, or anything else that you wanted to measure.

Representative HOLIFIELD. So we do have the technical equipment for accurate measurements?

Colonel HARTGERING. The technical know-how is available to determine where we are, what levels are accumulating in people, foodstuffs and anything else you would like to measure such as water supplies.

Representative HOLIFIELD. You are confident in the accuracy of your techniques?

Colonel HARTGERING. Yes, sir.

Representative HOLIFIELD. There is no controversy among doctors and scientists on this problem?

Colonel HARTGERING. No, sir. This is a straight principle of radiation physics, and I think it is generally accepted.

Representative HOLIFIELD. Thank you, sir. Your testimony and the submitted material you have given us will be very valuable. I am sure the doctors in the United States, as well as the public, will find it valuable.

Thank you very much, Colonel.

Colonel HARTGERING. Thank you, sir.

Representative HOLIFIELD. Our next witness is Dr. Hardin Jones of the Donner Laboratory, University of California, Berkeley, Calif., who is going to talk to us on somatic effects. Dr. Jones has been before this committee several times and we are glad to have him again.

I might say that on the basis of Dr. Jones' competence, he is professor of medical physics and physiology, assistant director of the Donner Laboratory. He was associated with the Lawrence Radiation Laboratory since 1937 which gives him, as I figure it, about 22 years of experience. He studied radiation effects since 1939. He has other fields of competence in the area of cancer, heart disease, biostatics, biophysics, circulatory physiology and other areas.

We are glad to have you before us, Dr. Jones, and we look forward to your testimony.

TESTIMONY OF HARDIN JONES,[1] DONNER LABORATORY, UNIVERSITY OF CALIFORNIA, BERKELEY, CALIF.

Dr. JONES. Thank you, Mr. Holifield.

Representative HOLIFIELD. As you know, we are running a little bit behind.

Dr. JONES. Yes. I would like to deviate from my prepared statement and summarize as much as I can. I wonder if it would be possible to have two of my lantern slides shown. (Figs. I and II, pp. 596 and 597.)

Representative HOLIFIELD. Certainly. Your entire statement will be inserted in the record at this point.

(Dr. Jones' prepared paper follows:)

OPINION CONCERNING EFFECT OF HYPOTHETICAL ATTACK RESULTING FROM THE USE OF 2,000 MEGATONS OF FISSON IN WEAPONS

Perceived at this moment, the catastrophic destruction of us and our abodes through nuclear warfare seems too overwhelming to proceed further. Under the probable assumption of some survivors, it is possible to estimate their state. A few would have sustained little direct exposure, but they presumably would be a small fraction of the survivors. In addition to ionizing radiation exposure, there would be thermal burns, blindness, deafness, trauma and pestilence. Perhaps we may assume that the rural population, unexposed at least to the violence of the explosions, would shelter the small fraction of urban survivors, and that overall the greatest effect on those surviving the immediate events would be radiation injury.

1. First we can estimate that accurate monitoring of exposure would be inadequate for the circumstances and that perhaps half of the population would die from a combination of radiation exposure and associated disturbances.

2. Most of the long-term survivors would be relatively incapacitated for a period of several weeks.

3. Lifespan effects: Those managing to survive, perhaps 5 to 20 percent of the entire population, would have sustained the following estimated exposures:

(a) About 300 r. whole-body radiation within the first week after attack.

(b) About 100 r. of additional exposure the first year.

These exposures will result in a life-shortening effect estimated to be about 10 days per roentgen. Lifespan reduction or radiation-aging will amount to about 400×10 or 4,000 days or 11 years. (For large exposures, given at a high rate, there is much less doubt about the magnitude of lifespan reduction. It can be directly estimated from the atomic bombing of Japanese. In this case, it seems reasonable to select the factor 1 r = −10 days for lifespan reduction rather than 1 r = −15 days. The difference possibly is associated with other trauma.)

4. Over and above the lifespan reduction effects there may be a serious bone tumor problem for U.S. residents from radiostrontium and for other people in similar target areas. For example, the estimated lifetime exposure of 3,500 rad for those who would continue to live in parts of the eastern United States. Other survivors would have bone exposures ranging down to the Northern Hemisphere average of about 70 rad. At this level bone tumors may have increased and, if so, about 1.5 times their usual incidence, a matter considerably less urgent than other effects of the nuclear war, but an effect involving the world's population.

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[1] Professor of medical physics and physiology; assistant director, Donner Laboratory; associate director, Institute of Human Development. Associated with the Lawrence Radiation Laboratory since 1937. Have studied radiation effect since 1939. Other fields of competence include study of cancer, heart disease, biostatistics, biophysics, and circulatory physiology.

APPENDIX A

HUMAN BONE AND WHOLE-BODY EXPOSURE TO RADIOSTRONTIUM AS A RESULT OF USE OF NUCLEAR WEAPONS

The exposure of human bones to radiostrontium has frequently been estimated from the fact that the highest levels of Sr^{90} observed in 1954–56 were about 1 $\mu\mu c$ per gram of calcium or per 7 grams of bone or an exposure of about 2.8 millirads (mrad) per year to bone. Since 1956 most radiostrontium analyses on human bones have been close to 1 or 2 $\mu\mu c$ Sr^{90}/gm Ca (1, 2, 3). Estimations of recent exposure to bone have been 2 to 6 mr per year to bone, or an increase above natural radiation exposure (taken at 100 mrad/year) of about 4 percent.

An additional factor producing radiation is the strontium 89 isotope. It is shorter lived but is initially relatively more abundant. This 54-day half life isotope enters the food chain sufficiently to have produced a radiation exposure in human bones nearly as great as that of strontium 90; that is to say probably 2 to 4 mr per year for the past few years. Because of the relatively shorter half life of Sr^{89} in comparison to Sr^{90} (54 days and 25 years, respectively), radiation exposure due to Sr^{90} will probably in the long run always exceed that from Sr^{89}. Since the contributing radiation from each to human bones has been nearly identical, estimations of bone exposure to date, based upon Sr^{90} alone should be approximately doubled, and a better estimation of radiation exposure to bone is about 7 percent instead of 4 percent as a rough guess for the average child during the past few years.

These rough averages of radiation exposure to bones should not be used to estimate exposure to bones soon to be experienced. Such estimations require additional methods and information. One such estimate follows: Figure 1 shown the concentration of strontium 90 according to age of child by calendar time. If attention is drawn to the relative concentration in a comparison at a given calendar time using a cross section of ages, it is then apparent that the year-old child has the highest concentration of Sr^{90}. It is, however, incorrect to assume that older children have eliminated Sr^{90} or that they will continue to remain at this relatively low concentration. A tracing of children developing from a common relative age shows that all children are increasing radiostrontium concentration and, indeed, the best estimation of Sr^{90} concentration in newly formed bone indicates that concentration is about the same in all growing children at a given date.

A physiologic model of bone formation has been the basis of the analysis of the growth of Sr^{90} in children's bones. The model's assumption is only that increments of bone growth from dietary minerals is much greater than replacement of formed bone. Radioactivity taken into recently formed bone will be diluted when ashed by the lower Sr^{90} content of bones formed in earlier periods when strontium 90 was less abundant. Figure 1 shows that all children are increasing their bone's radiostrontium content. Open circles shown in figure 1 are the only children's bones reported for 1958. The data are drawn in composite from England and the United States (1, 4, 5).

A second step in the construction of a model that may be used to project future Sr^{90} concentration is obtained from a comparison of concentration of Sr^{90} in milk and newly formed human bones from the same locality. Figure II shows that these two concentrations are about the same at corresponding times of observation. The fact that milk and newly formed bones appears to have the same concentration of Sr^{90} does not rule out the possibility that relatively less strontium than calcium may be taken from cow's milk to chilren's bones (discrimination against strontium). Vegetable foods having much higher concentrations of strontium and Sr^{90} relative to Ca could enhance Sr^{90} uptake by about the same amount as is gained in the cow's milk to human bone discrimination step. Alternatively, these questions are still sufficiently unresolved to allow the possibility of little discrimination against Sr^{90} from the specific activity concentration in milk to that of newly formed bone in children drinking that milk. The important point here is that the average dietary balance existing now establishes Sr^{90} concentration in newly formed human bones to be approximately the same as contemporary concentration of Sr^{90} in cow's milk.

An additional supporting point for the use of cow's milk Sr^{90} as a guide to human bone Sr^{90}, is the fact that the studies at Harwell establish a remarkable concurrence between the elemental ratios of strontium and calcium in milk and in human bones both averaging 250 μgm Sr/gm Ca (5). The elemental ratios are important because they can be used to estimate ultimate levels of radiostrontium

unaffected by some of the errors that may be introduced by temporary delays of entry of Sr^{90} into the food chain. This suggests that milk is an acceptable indicator of the level of Sr^{90} in newly formed human bone.

Using elemental strontium/calcium ratios as a guide to discrimination that may ultimately buffer against the entry of fallout Sr^{90} into human bones is the following comparison of this ratio from the Harwell study (5):

Grass	2800 μμgm Sr/gm Ca.
Sheep bones	580 μμgm Sr/gm Ca.
Milk	250 μμgm Sr/gm Ca.
Human bones	250 μμgm Sr/gm Ca.

Direct fallout of radiostrontium onto grass near Harwell, England, accounted for about one-half of the radiostrontium content of grass (5). Ratios of Sr^{89}/Sr^{90} in grass, rainfall, and soil suggest that one-half was derived from soil and rain, respectively, during May 1956 to January 1957 (5). The general evidence for increased Sr^{90} in the food chain during 1957–58 may reflect such a direct fallout, and on this basis, it may subsequently lower as contamination of the food chain is less from direct fallout onto plants. These matters are difficult to predict and in this instance it must be kept in mind that these levels are resulting not from single tests but from a relatively large number of tests over about 2 years. In this circumstance present levels may actually increase as the food chain comes into a more stable equilibrium with Sr^{90} in the soil.

For the purpose of estimation of radiation exposure to the bone now, at full effect of the Sr^{90} now available to the earth surface, and in the event of military action with nuclear weapons, the following information is in order:

I. Bone exposure

(*a*) While most human bones have less average concentration of Sr^{90} than 3μμc/gm Ca, it appears that newly formed bones and bones formed in children developing at this time will follow closely the concentration of Sr^{90} in milk (food use remaining as it is).

(*b*) Estimations of bone burdens soon to be attained by all individuals in the United States may then be placed at about 10μμc Sr^{90}/gm Ca. (Some areas have lower values and some have much higher values than this.) This average level corresponds to an additional exposure to bones of about 28 mrad per year and to $28 \times 50 = 1{,}400$ mrad=1.4 rad to the bones over a 50-year span of life. Natural radiation exposure to bone by 50 years of age, largely the sum of external radiation, would be about 3.5 rad.

(*c*) The estimated equilibrium value for residents of the Northern Temperate Zone of about 10μμc Sr^{90}/gm Ca corresponds to an earth burden from about 100 megatons of fission explosions.

(*d*) If in a war in which there is an exchange of nuclear weapons, and 2,000 megatons derived from fission were available for worldwide dissemination beginning from the Northern Temperate Zone, then humans, surviving and eating the same kinds of foods as are available now would accumulate an estimated bone burden of 200μμc Sr^{90}/gm Ca and a lifetime exposure to bones estimated to be 28 rad.

(*e*) These estimates may be too low. For example, the Machta statements, "Explanatory Notes on Worldwide Fallout and Long-Term Hazard," Washington, June 10, 1959, states, "each megaton equivalent of fission produces an amount of Sr^{90} which, if uniformly distributed over the earth, would give 0.5 mc/mi^2." Using this as a basis of estimation, worldwide average fallout would be about 1,000 mc Sr^{90}/mi^2 which is about equivalent to 1,000 μμc Sr^{90}/gm Ca in either milk or human bones. On the other hand, Machta's report that, "about 20 percent of fission is available for worldwide dissemination," would place the estimate paragraph (*d*) in close agreement.

(*f*) Large areas, perhaps 10 percent, of the United States would have received local fallout from nuclear explosions contaminating agricultural land with 10,000 mc Sr^{90}/mi^2 and higher. Individuals subsisting in these areas afterward could receive upward of 10,000μμc Sr^{90}/gm Ca in their bones or a lifetime exposure of 1,400 rad.

II. Whole-body exposure

(*a*) Immediate exposure: Unsheltered exposures almost anywhere east of the Mississippi River could produce lethal effects. We can assume that the majority of "partially sheltered" survivors in this area have received several hundred roentgens but perhaps less than 400 r. Individuals accumulating more than 400 r. may be considered to have little chance for surviving.

(*b*) Over the subsequent year after the nuclear attack some movement in the open on the part of survivors will cause them to accumulate about 100 r. additional exposure, but received without overt sickness.

LIFE SPAN REDUCTION AND SOMATIC EFFECTS INCURRED BY EXPOSURE TO IONIZING RADIATION

Life span reduction associated with an enhanced risk of death occurs without exception in experimental animals exposed to several hundred roentgens of ionizing radiation. These effects are known to occur at chronic continuing exposures that are greater than one roentgen per day in proportion to exposure, and also in proportion to large exposures received singly over a short period of time.

Estimation of radiation life-shortening in humans depends in part upon the use of an analytical model of the biology of aging (Jones, JCAE congressional hearings, June 1957) in which it can be shown that relative aging measured by increased incidence of degenerative disease occurs at the same rate regardless of animal specie when time lived is considered in life span units. This model, when applied to animal populations that have received single exposures, 100 r. to 1,500 r., suggests that life span has been reduced about 2.2 percent per 100 r. On the human time schedule, each roentgen of whole-body radiation received ages that person by about 8 days and this estimate holds over the entire range of exposures above 100 r. in those observations that have involved animals surviving beyond the period of acute radiation injury. These estimates are also in good agreement with followup of Japanese exposed to atomic bombing. In this instance, the higher death rate of atom-bombed Japanese corresponds to an "aging effect" directly suggesting that 1 r.=—10 to —15 days. Thus both methods of estimation are in close accord. In the case of the exposed Japanese, exposure includes other events including economic disturbance, burn, trauma, and permanent implantation of foreign bodies in the body tissues. These latter effects may account for the apparent excess of mortality risk in the atom-bombed people. For the purpose of estimating overall life span reduction of H-bomb exposees, the crudely estimated aging constant appears to be suitable. This would be 1 r.=—10 days for humans receiving more than 100 roentgens of radiation.

For periods of weeks to months after these postulated explosions of nuclear weapons, exposure would still be acquired. It is not so likely to contribute to radiation sickness, but it would probably add another hundred roentgens to the average exposed person. There is some evidence that this exposure may have relatively less life-shortening effect per roentgen. Evidence now available also justified adherence to the same aging effect per unit of exposure within a wide range of rates of exposure. Estimations made in the case of this opinion are on the basis that the long-term radiation effect is the same per roentgen regardless of exposure rate.

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FIGURE I

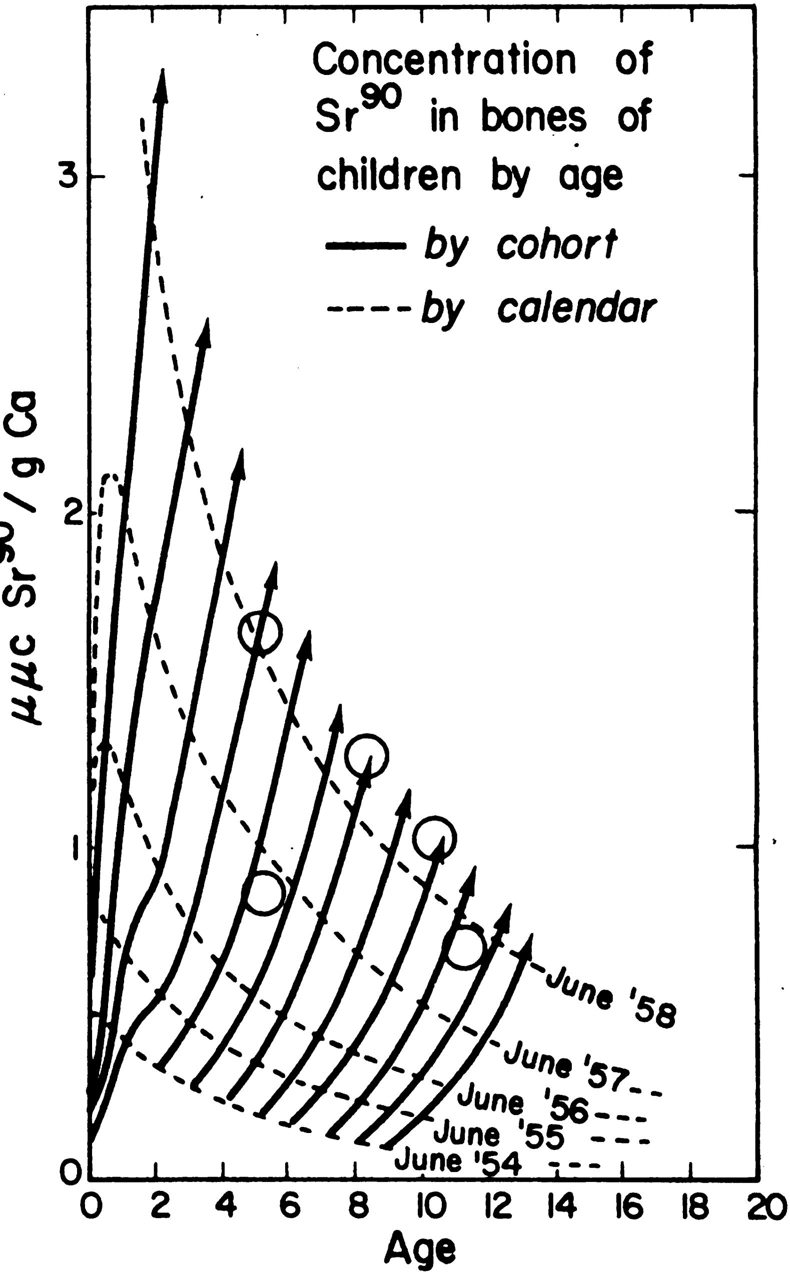
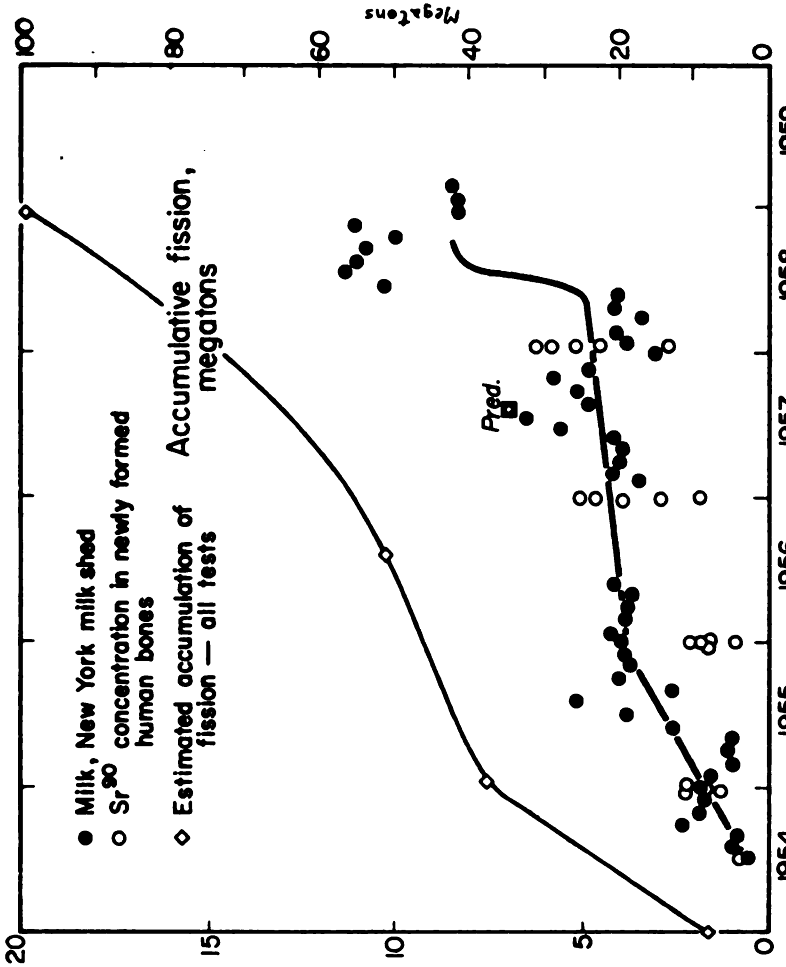

Concentration of Sr^{90} in bones of children by age
by cohort
by calendar
$\mu\mu c\ Sr^{90}$ / g Ca
June '58
June '57
June '56
June '55
June '54
Age
0
1
2
3
0 2 4 6 8 10 12 14 16 18 20

FIGURE II


Milk, New York milk shed
Sr^{90} concentration in newly formed human bones
Estimated accumulation of fission — all tests
Accumulative fission, megatons
Megatons
Pred.
0
5
10
15
20
20
40
60
80
100
1954
1955
1956
1957
1958
1959

Dr. JONES. First of all, some of the isotope effects from fallout such as strontium 90 might be viewed in a little more detail than is usually the case. I have prepared two slides (Figs. I and II, pp. 596 and 597) that are in similar form to what I presented to this committee the last time I was in Washington. Part of our concern in estimating the total effect of nuclear warfare is to be based upon extrapolation from today's experience in the appearance of radioactive strontium in human bones. Those who cannot see the board will also find this particular graph on the last pages of my prepared testimony. The usual way of presenting the distribution of radiostrontium in bone is as a function of age of the individuals at any calendar year. When you do this it is usually found that those bones of individuals 6 months to a year and a half old have the highest levels. As one examines older individuals in comparison the concentration of radiostrontium falls off. To the average person this may indeed give the impression that the amount of radiostrontium is decreasing in older individuals.

This is not the case at all. If we utilize all that is known now, say beginning from 1954 through the end of 1958, and present distribution of radiostrontium in bone by calendar year, then we can utilize the calendar year concentration distributions to establish what is happening to radiostrontium in individuals according to birth age. In life table techniques the term used for this kind of treatment is by cohort. In other words, these cohort lines represent the actual growth of radiostrontium in individuals. Each is following a given cohort pattern with time. These are the heavy lines seen on the lantern slide.

You notice each individual child as he grows older is putting down radiostrontium at the same rate and heading toward the same levels. The younger children do at any one moment in time also show the highest concentration of radiostrontium. It is a very easy step from this as a physiologist to calculate what the level of radiostrontium is in bone that is being newly formed in any child. When one does this he finds that radiostrontium concentration in new bone is the same, regardless of the age of the children. I might say that this is composite information from all bone analyses done in the United States and in England. The open circles happen to be the only measurements that are available this year reported from the New York operations office for bones of children in New York State. So you can see that the bones of children in New York State corresponding to the year late 1958 do correspond to this diagram rather completely. Could we have the next slide, please?

This shows the situation in comparison now, not calculating where these children happen to be on the average by age, but the concentration of radiostrontium in newly formed bones. Against this I have plotted in contemporary time the concentration of radiostrontium in the milk of the New York milkshed. Since most of the children's bones were obtained in the New York area, this is a fair comparison. The open circles in comparison to the black dots are the concentrations of radiostrontium in newly formed bones of children. You can see that it overlaps quite remarkably the average concentration of radiostrontium in milk in contemporary time. We can also use another approach that has been used in studies in this country and England, that is to calculate the elemental ratios of strontium to calcium in either bones of children or bones of adults, milk, cattle bones and the like. When this is done it is found that the elemental ratio of stron-

tium to calcium is the same for milk as it is in human bones and children's bones on the average. This method, based upon equilibrium conditions, avoids some of the errors that are encountered in estimating the time radiostrontium came into a certain food chain. This can be a very great source of error, and it is avoided by the elemental ratio method. It corroborates this particular diagram, telling us if we want to have a rough guess as to where all of us will be eventually with regard to radiostrontium concentration, some relatively short time from now, we can use the milk values as a guide.

Representative HOLIFIELD. Let me ask you, at this time, please, Dr. Jones, for the record to state what equilibrium is.

Dr. JONES. Equilibrium in this case would mean when all the radiostrontium now available to the food chain has become distributed between earth, food, and human bones. New fallout takes a while to get through the food chain to bones.

Representative HOLIFIELD. This pertains strictly to milk, does it?

Dr. JONES. I want to interject the statement that even though one makes this comparison it is still much better to drink milk for this purpose of attaining the least radiostrontium entering human bones than, for example, vegetable foods. It is many times better to drink milk.

Representative HOLIFIELD. Will you explain why?

Dr. JONES. This is because the radiostrontium concentration with respect to other alkaline earth such as calcium is much more concentrated in vegetables than in milk. If one eats vegetables predominantly then the level in human bones will be expected to be correspondingly higher. In the case of milk, one is laying down alkaline earth salts including radiostrontium from a lower concentration in the alkaline earths of milk.

Representative HOLIFIELD. Do you relate that to the megatons on the right?

Dr. JONES. Yes.

Representative HOLIFIELD. If you do, would you translate that into terms of 1,500 megatons and give us what your calculated readings are on that, if you have any, on the next slide? I may be anticipating you. Then will you give us that relation to the maximum permissible dose.

Dr. JONES. As you know, in the last 18 months the radiostrontium levels in the food chain and in human bones, too, have almost doubled in this country and countries throughout the world, and one might expect it would go up even beyond this. So if we take the current levels today which happens to correspond to about 10 micromicrocuries of radiostrontium per gram of calcium in newly formed bones—these are also known as strontium units—this would give us a pretty close index because milk values given this concentration, as to where nearly all human bone values will be, say, 10 or 20 years from now.

Representative HOLIFIELD. That is assuming we follow the same rate of bomb testing as we have.

Dr. JONES. This is assuming no further bomb testing.

Representative HOLIFIELD. This is assuming no further bomb testing?

Dr. JONES. Yes, sir.

Representative HOLIFIELD. On the other hand, if we do continue the rate of bomb testing, if this cessation agreement does not materialize and we go ahead with additional bomb testing, does that mean this rate will go up, and if so, how much?

Dr. JONES. This rate will go up. This equilibrium value projected from today, which is about 10 micromicrocuries, on the average for the world corresponds to 100 megatons now released into the world. According to the argument we are prepared to discuss today, we are discussing 2,000 megatons, which is a factor of 20 higher than this. In this event we would estimate bone exposure to correspond to 20 times our present level of 10 micromicrocuries per gram of bone calcium. This may be used as an estimated world average.

Representative HOLIFIELD. Our actual world total in the exercises is 4,000 megatons, which would be the reading you would want, would it not? 1,500 in the continental United States?

Dr. JONES. I refer to 2,000 megatons of fission. Not the fission part—the fission alone produces the radiostrontium. This will still give a relatively low exposure as far as bones of the average person are concerned. The 2,000 megatons of fission will correspond to something of the order of a 50-year lifetime exposure of perhaps 28 or 30 rad to the bones of people in the northern hemisphere for an indefinite period to come, perhaps for a period of a century.

Representative HOLIFIELD. Can you tell us what that type of exposure will do to bone cells?

Dr. JONES. Yes. As one of the proponents of proportionality estimation of cancer induction by radioactivity, I would say that if these concepts turn out to be correct, in this low exposure range, this might increase the number of bone tumors in the world by 70 to 100 percent. It does happen fortunately that bone tumors are one of the less frequent of tumors so that one might increase bone tumors from 1 percent of all tumors to about 2 percent of all tumors. But there are considerations, too. and especially in terms of the immediate fallout pattern that would produce areas of much greater concentration of fallout near sites of weapons detonated.

Representative HOLIFIELD. So the figures you have given are based on a worldwide average and not on the hot spots which would occur.

Dr. JONES. Yes. I calculated in certain easy ways that are subject to moderate plus or minus corrections, that about 10 percent of the eastern seaboard would have radioactivity from strontium 90 so intense that if people lived there and ate food that was produced in these areas, they would have many times this bone level. If 10 percent of such people settled in these areas, assuming they were not warned away, they might develop lifetime exposures of several thousand rad to the bone. Of course, in still more limited areas radiostrontium might go up even more than this. Several thousand rads could mean that the bone tumor would become very definitely a realistic problem. These individuals might have a 50–50 chance of developing bone tumor over a lifetime. We are still uncertain of some of the magnitude of some of these effects in humans.

Representative HOLIFIELD. As you have pointed out, the children who are in the skeletal forming stage of their life would absorb more of this than an adult who had passed the major part of his skeletal forming period.

Dr. JONES. Yes. If I can briefly turn our discussion to the life span effects and the somatic effects which I primarily wanted to discuss——

Representative HOSMER. Before you do that, on your first chart there if we can put it back on, your very young children less than a year old had a greater concentration.

Dr. JONES. Yes.

Representative HOSMER. The bone is being formed. Why does it drop off when they grow older?

Dr. JONES. This is because fallout has been increasing very rapidly in recent times. Children that were already partially grown by the time they were exposed to a given concentration of radiostrontium are taking in radiostrontium, in the forming of new bone. But the whole bone arch one is diluted in radiostrontium content by bone that did not have any radiostrontium built into it. Hence we get an apparent dose which is not real if you base the value in terms of using this information to project where humans will be after a period of time.

Representative HOSMER. In other words, you are not following one child through 8 years but you are taking a group of 7-year-olds, 6-year-olds, and so forth.

Dr. JONES. It doesn't make any difference what age you start because any age child will eventually catch up in radiostrontium level. Even the denser bone has a finite turnover and will eventually turn over. For a period as brief as 10 years, this turnover is of very little consequence. Slow bone turnover does show up as a dilution factor in partially grown children today.

Representative HOSMER. But the child that is 1-year-old today and has a higher concentration will as time goes on become higher.

Dr. JONES. Yes, sir.

Representative HOSMER. And not lower as you might think by looking at that chart.

Dr. JONES. Yes.

Representative HOSMER. Thank you.

Dr. JONES. It is really very difficult today to come to a final understanding as to what the life shortening effects of radiation, given as whole body radiations to human beings, may be. We do have, however, certain reasonable information to go on. Many of these studies have been conducted at the National Institutes of Health by Lorenz and also the atomic energy establishments, especially those in Rochester and including the work of Harry Blair. I myself have collected no primary data bearing on life span but as an interpretative biologist I have used existing information to give what I believe is a fair interpretation. All of us are trying to be as objective as possible. If we were fully objective, I think some of these problems could be resolved more readily. I cannot prove whether I am more objective than anyone else in this. I do perhaps have some different viewpoints.

Representative HOLIFIELD. That is why we are going to have this panel later on to put the various degrees of subjectivity and objectivity to test in a crucible of debate.

Dr. JONES. Life span effects cover quite a range. Some measured lifespan observations are in laboratory animals such as mice or rats or guinea pigs or rabbits—this information was collected in recent

time on a fairly sizable scale. There is no difficulty at all in establishing that lifespan shortening occurs in the higher dosages, say from 100 roentgens of the whole body exposure, up to 1,500 roentgens of whole body exposure, in proportion to the amount of exposure that was given these animals. There is a reasonable model that we can use to translate these effects to man. It turns out that if we do this that approximately 100 roentgens of whole body radiation given as a single dose over a relatively short period of time means about a 2-percent loss in lifespan as though the animal became older.

To shorten our argument, if we take all the available evidence about this value and translate it to estimated effect for humans, the information would mean that radiation exposure above 100 roentgens, for each roentgen that is received, shortens the lifespan by about 5 days to perhaps more than 10 days. I have estimated the median figure about minus 8 days per roentgen of exposure on the human lifetime scale.

Representative HOSMER. At that point, will you explain what it is that shortens the lifespan? Is it general deterioration, or is it an average that somebody would lose 10 days and somebody would lose 5?

Dr. JONES. It is a statistical average. To understand the arguments, it would be best approached in terms of a statistical comparison.

Representative HOSMER. Does it mean somebody will have a heart attack and somebody will have a lung cancer and somebody will have something else, or does it mean that thereby you reduce each individual's lifespan? Is that the way the statistic is arrived at, or does it mean that anybody getting such a dose will positively be reduced by that period of time?

Dr. JONES. It certainly does not mean that anyone getting any dose is positively going to have an effect. It means the probability of having one effect or another associated with aging is increased. The remarkable thing about lifespan effects with the possible exception of the involvement of leukemia is that the probability of all kinds of degenerative diseases increased by a proportional factor as one becomes irradiated. But irradiation is not unique in this. If we had time, I could show you at least 20 different conditions that are associated with aging and shortening of lifespan just like irradiation. This includes such things as cigarettes, disorders of hypertension, obesity, way of life, and so on. As a best guess, from our model of aging, using all the small animal data available and carry it over to man, lifespan effects are somewhere between minus 5 and minus 10 days per roentgen at high exposures. We can consider large population studies available to us where humans have been exposed, as in Japan where there were populations followed up after atomic bombing. It is very difficult to reach secure conclusions since there are many limiting reasons as to why this information is not fully reliable. Nonetheless, this is the only human information that there is to work with and the first approach may be to see how reasonably these observations agree with information obtained from laboratory animals.

What one finds in the study of these Japanese is that first of all leukemia is increased just as in the case of other smaller populations that have been followed after exposure to radiation. This observance is beyond argument. We also find if we compare it to the small animal

studies that have been conducted in which lifespan measurements that have been made that the thing that is outstanding in addition to the lifespan effect is that leukemia and leukemialike diseases are increased in the small animal. This information fits together quite remarkably.

The other finding in the Japanese studies is that, in addition to the leukemia, the crude data support an overall increase in all kinds of cancer. This is the other thing that one finds in experimental animals. One finds an increase of all kinds of cancer in addition to leukemia. As a matter of fact, in the small animals one is certain that there is an increase in cancer, a doubling of the cancer rate in small animals, by as little as an accumulation of 30 roentgens. In this case, not given all at once but at a protracted low exposure rate, which if we were generalizing would be the least likely condition for cancer to be associated with ionizing radiation exposure. So far the information from Japan fits exactly with other information. If one takes the next steps, according to life table comparisons within the substructure of the Japanese population that was exposed to varying degrees or in comparison to certain control population samples that were selected, one always finds that there is a higher death rate among those exposed and a higher death rate in proportion to degree of exposure in the aftermath since the atomic bombing.

Representative HOLIFIELD. In both of these instances are we talking about substantial radiation exposures when we talk about the Japanese cases and when we talk about the animal cases in the laboratories, is that correct?

Dr. JONES. That is right.

Representative HOLIFIELD. Could you give us an idea as to the number of roentgens you are talking about?

Dr. JONES. We are talking about perhaps an average dose to the several exposed populations that may be something about 300 roentgens of whole body radiation. We are talking about a range in this group that may be somewhere between 100 roentgens of whole body radiation, perhaps upward to 500 roentgens of whole body radiation.

Representative HOLIFIELD. In the case of the animal experiments, what are you talking about?

Dr. JONES. We are talking about a range that runs somewhere between 100 roentgens of whole body radiation up to 1,500 roentgens of whole body radiation. Survival in case of this high level exposure depends on tricks to tide animals over the acute effects period. If animals were not so treated, the animal studies would be more comparable to the range observed in Hiroshima and Nagaski.

Representative HOLIFIELD. In other words, where you do give that larger dose to the animal you use some kind of therapy to keep them alive?

Dr. JONES. Yes, for the acute period.

Representative HOLIFIELD. What does that involve? Transfusion?

Dr. JONES. Transfusion, bone marrow sedimentation, shielding of the spleen, and giving antibiotics and things of the kind that were not available to the Japanese after the atomic bomb exposure.

Representative HOLIFIELD. What would your experience be with animals if you used, let us say, low dose rates. When you say low dose rates I will start in with the background radiation of 7 roent-

gens in 70 years, or let us take five times that and say 35 roentgens in 70 years. Would you have, in that type of exposure, detectable and observable damaging effects to form a statistical concept of the hazard?

Dr. JONES. If we use generation of tumor in experimental animals such as mice or rats as the basis of making this comparison—it happens that we can go in this direction with more precision—then I would say it doesn't make any difference whether you give the radiation all in one amount or let it be accumulated at a very small amount of exposure. In this case, the life span reduction or the carcinogenic effects will turn out to be the same regardless of dosage rate in this case.

Representative HOLIFIELD. You did not quite answer my question, did you?

Dr. JONES. I was going to the next step, sir. If, however, we take the information such as it exists from the whole experimental work at this time in terms of life span reduction, which is much more difficult to measure than the generation of cancer, then we find several circumstances of observation where animals have been exposed to low dosage rates such as a tenth of a roentgen per day or even one roentgen per day or four roentgens per day there has been no measurable life span reduction.

As a matter of fact, some of the observations have even produced life span lengthening as far as that experimental observation is concerned. If you examine this, however, one would find without exception that the numbers of animals involved are too small to have tested the point possible of life span effects either as to whether there was life lengthening or life shortening. But nonetheless if one tries to accumulate all the information now available, which means perhaps 24 or 25 sets of information on small animals where one has available dosage rates, there are enough small dosage rates that are associated with a lack of a finding of life span reduction that allow the possibility that at the low dose rates there the life span reduction effect is perhaps much less than at the intensely given exposures.

Representative HOLIFIELD. You spoke of one-tenth roentgen exposure per day in these measurements.

Dr. JONES. Yes.

Representative HOLIFIELD. For how many days?

Dr. JONES. This went on essentially for the majority of their lifetime or until they died.

Representative HOLIFIELD. In other words, a number of years.

Dr. JONES. A year to a year and a half.

Representative HOLIFIELD. How does that compare with the background radiation which we get, the natural background radiation?

Dr. JONES. A tenth of a roentgen per day is approximately thirty times natural background radiation.

Representative HOLIFIELD. Per day?

Dr. JONES. Yes. Natural background radiation is about three-thousandths of a roentgen per day.

Representative HOLIFIELD. How does it compare with the addition of bomb test buildup radiation?

Dr. JONES. The accumulation of background radiation buildup is perhaps close to 10 percent of natural radiation at the present time.

That, in part, depends on who figures it, as to whether it is given as about 4 percent or whether it is close to 10 percent.

Representative HOLIFIELD. What would that mean? Give me a quick calculation. You are better in mathematics. You gave me three one-thousandths as being the natural background.

Dr. JONES. Per day.

Representative HOLIFIELD. As being the natural background radiation average. Now give me in ten-thousandths. What would it be?

Dr. JONES. It would be about ten.

Representative HOLIFIELD. About 10 ten-thousandths?

Dr. JONES. No, I am sorry. It would be 3 ten-thousandths rad per year due to internal emitters that we have accumulated, plus increase in background radiation and so on.

Representative HOLIFIELD. This is internal?

Dr. JONES. This will be largely internal but it also would include some peak exposures from immediate external fallout that has already occurred. I don't think the going rate today is necessarily this high. Part of this higher value is due to inclusion of certain peak exposures coinciding with some immediate fallout after each bomb blast.

Representative HOLIFIELD. The one-tenth roentgen exposure per day, was that an internal injection in the mice?

Dr. JONES. That was external radiation.

Representative HOLIFIELD. Was it for the whole body?

Dr. JONES. Essentially for the whole body.

Representative HOLIFIELD. We are talking about the same thing. We drop from one-tenth roentgen per day of whole body radiation to 3 one-thousandths roentgen and we are talking about the same thing. We are talking about the same type of exposure?

Dr. JONES. We are talking about the same thing. However, even though there is no probable life span reduction at one-tenth of a roentgen per day, it is very easy to show that each time studies of this kind have been done, at a tenth of a roentgen per day, by the time that 30 roentgens of accumulated, which is within a year's time, the tumor rate in the irradiated animals is about twice the incidence in control animals and usually significantly higher than in the controlled animals.

Representative HOLIFIELD. That is a 30 roentgen accumulation?

Dr. JONES. Yes.

Representative HOLIFIELD. In the case of natural background radiation you would get 7 roentgens over a lifetime?

Dr. JONES. Yes.

Representative HOLIFIELD. Is that generally considered by most scientists as being an accurate interpretation?

Dr. JONES. Yes, I believe I followed you correctly.

Representative HOLIFIELD. Is there substantial disagreement to it?

Dr. JONES. No. This leads us into an area of interpretation of radiation effect where unfortunately we have no experimental verification of our theories about radiation effect. I think it is urgent to get some experimental verification. We seldom achieve model systems and theories that will enable us to extend ourselves relatively as far as we are being asked to do this in these circumstances in estimating effects close to natural levels of radiation exposure.

Representative HOLIFIELD. This subcommittee, as you probably know, and the full committee, authorized a 50 percent increase in the facilities for tests on animals, and this is part of our concern.

Dr. JONES. I am very glad to hear that because it is really a very urgent problem.

Representative HOLIFIELD. You made the statement that the number of animals used was too small.

Dr. JONES. Yes.

Representative HOLIFIELD. We received testimony yesterday that low dose studies had been made on some 18,000 mice or rats. Would you or would you not consider this a sophisticated experiment?

Dr. JONES. I would, yes. I am not aware of the study, sir.

Representative HOLIFIELD. That was in the testimony yesterday. I forget now who the witness was but you will find it in the testimony.

Dr. JONES. Yes, sir. If we use these values for life shortening from the crude observations in Japan which of course may be in considerable error, numbers for life span reduction have reasonableness in comparison with the small animal studies that have been conducted by a large number of investigators throughout the world. They turn out to be the same numbers. I would say, then, that this is the safest information we could use if we are going to project what would happen to atomic warfare survivors.

Representative HOLIFIELD. In talking about this attack, we are not talking about seven roentgens or seven-tenths of a roentgen. We are talking about thousands of roentgens.

Dr. JONES. Thousands of roentgens and at least hundreds of roentgens. Here there is more certainty that we are standing on sure ground. I think we are standing on sure grounds when we say that the life span reduction is very real and the carcinogenic effects are very real and we perhaps already know these numbers within a factor of two for high exposure effects of radiation in humans.

Representative DURHAM. You can extrapolate pretty accurately from that, can you not?

Dr. JONES. Yes. For biologic data, sir, a factor of two is very reasonable.

Representative HOSMER. Do the various animal experimenters agree on the factor they apply in animal tests to achieve human lifespan-shortening estimates?

Dr. JONES. I am sure that there is a wide variety of opinion in this. I know that Dr. Blair has in times past presented numbers that are quite different from mine.

As I last heard him talk, he presented the same numbers I have given.

Representative HOSMER. I thought you said the experimenters around the world generally agree on this.

Dr. JONES. I think there is some agreement in the numbers that I give you, yes.

Representative HOSMER. Do you tell me that you disagree on the factor of extrapolation, but agree on the result? How does that come about? Did the original experiments vary, or what?

Dr. JONES. Most disagreement in terms of lifespan reduction comes about at the present time in terms of watching animals for a short portion of the lifespan after they have received a very great ex-

posure, and exposure enough to produce radiation sickness. At this time the death rate becomes phenomenally high. So that if you——

Representative HOSMER. You were postulating this thing on 100 roentgens beginning and then an increase.

Dr. JONES. Suppose I calculate lifespan effects based upon death rates 30 days after radiation exposure and I give to begin with 800 roentgens for one group and then I give 800 roentgens in two groups separated by 2 weeks' time. Then the total exposure is 800 roentgens but at a lower dose rate. Then I would find the death rate at 30 days is comparatively reduced after fractionated exposure. I can fractionate the figure again and find that my death rate becomes lower and lower. If you use a system like this and a short followup observation instead of lifespan followup, you could then fit the observation of declining death rate associated with degree of fractionation exposure to derive a mathematical model which says that as you fractionate the dose more and more, eventually it won't have a lifespan effect. I do not believe this model is correct.

Representative HOSMER. In other words, there is a great difference between a prompt dose and an accumulated dose.

Dr. JONES. This is because 30 days is not far enough to separate the tremendous effects on death rate that have to do with being acutely ill. The situation is that you can have recovery from acute effects or not quite independent of these long-term effects that simulate the aging process.

Representative HOSMER. What I am getting at, Dr. Jones, is your rule that one roentgen equals a 5- or 10-day shortening. Does the rule apply in the case of prompt doses and not necessarily in the case of accumulated doses?

Dr. JONES. Yes, we are more certain of the effect at prompt dose exposure.

Representative HOSMER. Let us say 101 r. Under that accumulated basis is that at 100 roentgens is one more roentgen going to take 5 or 10 days off life?

Dr. JONES. Very likely. You have also hit on one of the other difficulties in lifespan observations. If you take animals that have received a fairly large dose, and, shall we say, if you then later on in their life give them more radiation exposure you perhaps can have them live long enough the effect of the second dose. If the second exposure is given a long time after the first exposure, then lifespan reductions many only be apparent from the first dose, and the one more roentgen in your example could then be without consequence on aging. Things of this sort can confuse the considerations involved.

Representative HOSMER. What I was wondering about is that "radiation may be good for you in easy installments" indicated by the testimony of Colonel Pickering yesterday.

Dr. JONES. I didn't hear Colonel Pickering's testimony. There is some other testimony that radiation can be good for you. It is very trickily conceived. It is the study on rats recently completed at the University of Washington. There is no doubt but that in this case rats that receive one roentgen per day to four roentgens per day live longer than rats in this colony that receive much less radiation exposure. There is, however, a very striking additional fact about this. These rats without radiation exposure have a very short lifetime be-

cause they all die of pneumonia and they die rather early in the course of observation from pneumonia. One thing that has been known for a long time about radiation exposure is that radiation exposure helped to combat infections. I think in this case there is an unrealistic situation as far as having a test animal that can simulate natural aging. The animal does not stimulate natural aging at all. It doesn't live long enough. In this sitution of chronic pneumonia which causes death in most animals, radiation lowers the risk from pneumonia more than it increases the risk of life shortening from aging. · You can have a choice then as to whether radiation has prolonged the lifetime of animals in a way that it would apply to humans. I believe it does not apply.

Representative HOSMER. I think we can agree that the life shortening of 5 or 10 days may be changed in some respect. It is not a definite proven clinical fact at this point.

Dr. JONES. A few roentgen per day stands relatively untested critically as far as the human population is concerned. There is only one population that can be tested in this way at the present time and that is the group that have been practicing radiologists. The radiologists have been looked at several times. If you put them together as a whole group you will find that there is not on the average a difference in life span or age at death between the radiologists and the nonradiologists physicians. But if you look at this group again critically one finds that the average radiologist has not been a radiologist very long and recently more and more have gone into the profession of radiology. So that the numbers of individuals who were there in the beginning who were the old ones who were irradiated are overwhelmingly diluted by the newcomers having very little exposure. If you attempt to study the old radiologists which you can do in part by calculating—not what would be the average death rate of the whole population of radiologists compared to whole populations of the other physicians but rather a mortality at older ages—then you do find that radiologists who are over 55 years of age apparently have a higher mortality than do physicians. Even though I have not made this calculation with my colleagues, I think the calculation ought to be done much more critically. As far as I know, no epidemiologist has gotten the primary data in hand to be certain about definition of the population of radiologists, their radiation exposure and death risk. I would say if one had to exhibit another population that does show radiation effect radiologists are an example and the results are in keeping with other things we know about radiation exposure.

Representative DURHAM. Tolerance is a great guide post that applies to most everything else.

Dr. JONES. Yes, there is room for a lot of tolerance.

Representative HOLIFIELD. This points up the cautionary principle of going very slowly in these low radiation fields in arriving at a definite black and white conclusion as to its effects. In other words, the field still needs a lot of experimental work and a lot of numbers to bring our statistics up to a meaningful point.

Dr. JONES. Yes. As a philospher I would say comparing the history the way other fields have moved that we are trying to make final conclusions when we need 10 times more information. But we have to make conclusions in the face of today's situation.

Representative HOLIFIELD. We have to use prudent judgment as indicated by such information as we have when the destiny of the human race is involved.

Dr. JONES. Yes.

Representative BATES. Do I understand, then, that you don't use the classical method of statistics in coming to a conclusion, that you do not have a sufficient number of examples to give a true indication of the error of probability?

Dr. JONES. We do wherever possible use the classic methods of statistics. We have to conclude in some circumstances that we do not have enough information to make great generalizations from our findings and even in some situations to know for certain whether the finding we have is real in terms of repeating the observation. Many of the situations that I have quoted, however, are not in that circumstance.

Representative HOLIFIELD. That is true. We are talking about a class of the knowledge. When you get up into the higher dose rates then you begin to get observable and detectable phenomena in the laboratories and in the field which are meaningful and which can very well be accepted.

Dr. JONES. Yes. Radiation induced lifespan reduction for a population surviving this imagined atomic attick probably is very meaningful at about a lifespan reduction of 10 years corresponding to about 300 roentgens of total body exposure. The effect might be 5 years or even 15 or 20 years. Ten years is probably a good guess. This means also a very great average reduction in vigor during life after exposure. This is a reduction in vigor to about 40 percent of the vigor that an average person would have for that chronologic age. I would say it may reflect a sizable effect on the ability of such people to do their work.

Representative BATES. I was wondering on that point whether in these averages you have computed do you have many extremes or do you have minimum deviation from the mean?

Dr. JONES. I have tried to give you average values. I have stayed away from giving you lower or upper extremes and give you average values unless I noted a range of values.

Representative BATES. Averages sometimes do not mean too much. The question was, Do you have considerable extremes or do you have small deviation from the mean?

Dr. JONES. For example, in calculating the lifespan effect, say, at 300 or 400 roentgens of whole body radiation for man I could under some circumstances be justified in taking only the animal data where the one roentgen is equal to minus 5 days. On the other hand, I would be equally justified in taking the flat value which one gets from the crude Japanese data which says for younger adults the lifespan reduction per roentgen is minus 15 days per roentgen. Here is a range of threefold. I took an entire population average value corresponding to 10.

Representative HOLIFIELD. Are you sure in taking that 15 days that you have a controlled base to start from in knowledge of the degree of exposure which the Japanene victim had?

Dr. JONES. These are not controlled observations; they are very rough data. I can only say that this is what I attempted for you in

the absence of refined evaluation of the effect of atom bombing on the Japanese.

Representative HOLIFIELD. If you did not, that shoots your theory full of holes.

Dr. JONES. Yes, there are uncertainties. I think you asked me to make the best estimate I could.

Representative HOLIFIELD. I understand.

Dr. JONES. I am not saying this is right. I am saying these are the numbers we have to work with and I believe there is a good interpretation of them.

Representative HOLIFIELD. Thank you very much, sir.

Our next witness will present testimony on the genetic effects of radiation.

Dr. Neel, will you please come forward to the witness chair.

Dr. Neel is professor and chairman of the Department of Human Genetics, and a professor in the Department of Internal Medicine of the University of Michigan Medical School. He has served as Acting Director of Field Studies for the Atomic Bomb Casualty Commission, the National Research Council, was a consultant on genetics for the Committee on Atomic Casualties, National Research Council in Japan.

I think you have a background which will justify us in hearing what you have to say, sir.

STATEMENT OF JAMES V. NEEL,[1] PROFESOR AND CHAIRMAN, DEPARTMENT OF HUMAN GENETICS, UNIVERSITY OF MICHIGAN MEDICAL SCHOOL

Dr. NEEL. Mr. Chairman and members of the committee, the task assigned me this afternoon is a formidable one. As has been amply brought out in previous testimony before this committee, the gaps in our knowledge of the genetics of man are tremendous. Because of this, widely different quantitative treatments of the genetic risks posed by the exposure of mankind to increasing amounts of radiation are possible. Indeed, so great is our ignorance on certain points that some geneticists have refrained insofar as possible from attempting to quantify the problem beyond certain very broad limits. This is on the conviction—and I quote from a monograph by Dr. Schull and myself—"that semiquantitative treatments are ill-advised, since except to the relatively few who have made a detailed study of the problem, they impart an air of mathematical exactitude and scientific accuracy

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Present: Professor and chairman, Department of Human Genetics, and professor, Department of Internal Medicine, University of Michigan Medical School, 1956–.
Other professional experience: Acting Director of Field Studies, Atomic Bomb Casualty Commission, National Research Council, Sept. 3, 1947–Mar. 31, 1948. Consultant in genetics, Committee on Atomic Casualties, National Research Council, 1947–51; on leave from University of Michigan, May 7, 1948–July 15, 1949; Aug. 9, 1950–Oct. 10, 1950; and Jan. 27, 1952–Mar. 28, 1952, for service in Japan.

to an area where the errors are sometimes large and often indeterminate." In my testimony this afternoon, I shall always give a reasonable upper limit and a reasonable lower limit to my estimates, but avoid the use of a single "best" figure which could be quoted out of context and made to look as if we knew far more than we do.

As is well known to this committee by now, the deleterious genetic effects of radiation are due to the fact that radiation produces lasting changes in the genes which we term mutations. On the basis of our present knowledge, it would appear that well in excess of 95 percent of all mutations—perhaps in excess of 99 percent—have deleterious effects. In thinking about the problem before us today, namely, the genetic effects of large-scale nuclear war, I would like to divide the question into two parts, namely (1) how many mutations will be produced by the resulting radiation, and (2) what will be the impact of these mutations on subsequent generations in terms of death, disease, and disability?

I would like to lead you through the first calculation in some detail, because I believe it's important in this vital area for the public to understand how we get at these risks. After this one detailed example, I shall only use summary figures. The number of mutations produced in a population by radiation and liable to transmission to the next generation is given by the equation:

(1)		(2)		(3)		(4)
number of exposed individuals contributing to next generation	×	number of genes each person possesses	×	probability of mutation per gene per roentgen unit	×	average dose received by each person

Let us consider first the genetic effect of the postulated situation on subsequent generations of American citizens. The Bureau of the Census in 1957 estimated that the number of individuals in the United States 39 years of age or less, from whom the next and subsequent generations will for the most part be drawn, is approximately 110,476,000. Let us assume some 40 million of them survive and are able to reproduce, and subsequent to the bombings, replace themselves with a like number of children.

I am sure I do not have to emphasize how arbitrary that 40 million is. I would much prefer to utilize figures derived by OCDM or some other competent group, but as far as I am aware, no such figures have yet been forthcoming in this testimony.

Let us place the number of genes in man at between 20,000 and 100,000, the lower figure being favored by the more conventional methods of estimating gene number, and the higher figure—or an even higher value—being favored by recent advances in our knowledge of the chemical structure of chromosomes. The probability of mutation per gene per roentgen unit will, on the basis of Russell's work on the mouse, be placed at between 1 and 4 x 10^{-7}. Finally, on the basis of the testimony thus far submitted at these hearings, we will assume an average radiation exposure to the reproductive glands of the survivors of 300 to 600*r*.

Again I must emphasize how arbitrary the selection of these figures is.

We will assume that the yield of mutations from radiation delivered under the conditions we are now discussing is the same as from acute radiation, although Dr. Russell's recent work raises some doubts on this score; in any event, we cannot make a realistic correction for this factor at the present time. The roughness and oversimplification of these assumptions requires no comment. On this basis, a very conservative estimate of the number of induced mutations to be transmitted to posterity, derived by using the lower figures all the way through, would be 24 million, while a more liberal estimate, derived by using the upper figures throughout, would be 960 million. The actual calculations are given in table 1 of this testimony.

TABLE 1. NUMBER OF MUTATIONS PRODUCED BY GIVEN EXPOSURE TO RADIATION

	(1) number of exposed individuals contributing to next generation		(2) number of genes each individual possesses		(3) probability of mutation per gene per roentgen unit		(4) average dose (r) received by each person		
LOW	40,000,000	x	20,000	x	$\frac{1}{10,000,000}$	x	300	=	24,000,000
HIGH	40,000,000	x	100,000	x	$\frac{4}{10,000,000}$	x	600	=	960,000,000

Representative HOSMER. Let me make sure I understand that. That means that eventually each of those mutant genes will show up at some birth.

Dr. NEEL. That means that there are this many genes to find expression in some way.

Representative HOSMER. Over what kind of a time span is that?

Dr. NEEL. Later on I shall use the working figure, 30 generations.

I have attempted to present this calculation in such a way that should later testimony supply better figures than I have used in these calculations, they can readily be substituted for my own, and more appropriate estimates derived.

I have not attempted a figure for the world as a whole because of the extreme uncertainty as to the number of persons involved and their integrated dose, but obviously it would be at least 2–4 times this value, depending on the mortality pattern which prevailed.

Now, it might be that the population of the United States, having been so decimated by the bombings, would increase at a rapid rate in the next generation. If the population doubled, to take a very extreme example, then, barring the immediate effects of selection, the number of mutations to be accounted for would double too. Likewise, if there were only 20 million fertile survivors and they replaced themselves with a like number of children, the number of mutations to be accounted for would be half the number given in table 1.

What, now, would these mutations mean in terms of death and disability in subsequent generations? Would that we knew. Some of them will result in very early death, either during the course of

the pregnancy or shortly after birth. Others will result in serious defects, present at birth or appearing as the individual ages. Still others will impair vigor and fertility in ways still difficult to define. We cannot specify accurately the relative proportions in which these different kinds of effects occur. As a very, very rough guide, we might estimate that 1 to 4 percent of these mutations would result in obvious abnormality which while consistent with a considerable life span, would constitute a significant handicap. Another 20 to 40 percent of these mutations are postulated to contribute to very early death, i.e., either during fetal life or during or immediately following birth. The remaining majority of the mutations, say 50 to 80 percent, will result in an impairment of vigor, of fertility, or a shortening of the life span, acting, as just mentioned, in an insidious and subtle fashion. A relatively few mutations—on the basis of our present knowledge not more than 1 or 2 percent—will be beneficial. The effects of these mutations, as you have already heard in previous testimony, will be spread over many generations, some finding their chief expression in the very first post-bombing generation, others not finding expression for 30 or possibly more generations. Table 2 summarizes this part of my testimony.

TABLE 2.—*Effects of the mutation produced by nuclear warfare on subsequent generations of U.S. citizens* [1]

	Low estimate	High estimate
Mutations resulting in obviously defective persons.*	240,000 to 960,000	9,600,000 to 38,400,000.
Mutations resulting in fetal or perinatal deaths*.	4.800,000 to 9 600,000	192.000 000 to 384.000.000.
Mutations resulting in persons with impaired vigor or fertility.*	12,000,000 to 19,200,000	480,000,000 to 768,000,000.

[1] These effects to be distributed over some 30 generations.

*The actual number of individuals exhibiting the effects of these mutations would be less than the figures given above. Thus, if 1 fertilized egg received 3 different mutations which in combination resulted in the failure of that fertilized egg to develop properly and so to a fetal death, that 1 fetal death would remove 3 mutations from the pool of mutations induced by the bombings.

You will see, if we follow the low estimate throughout, the number of obviously defective persons who might result from this experience, to be accounted for over a period of some 30 generations, would be 240,000. The number of early deaths might be 4,800,000. The number of persons with an impaired vigor or fertility of some type, 12 million. If we take the high estimate, the number of defective individuals could be as high as 38,400,000, with corresponding increases as regards the number of early deaths or the number of persons who function at an impaired level.

If, in the next few years, it develops that the gene number is much greater than I have assumed in this treatment, or the mutational yield from chronic radiation much different from that from acute, or the mutational spectrum significantly different from my assumptions, then even these wide limits are not wide enough. Incidentally, I should state that alternative methods of estimating mutational damage, such as those employed by Dr. Crow in earlier testimony, yield answers in this same range.

I should also point out that you cannot directly equate the numbers given in table 2 to persons showing defect or disability, since for

instance one person who dies at a relatively early age may show the ill effects of three or four different induced mutations. Thus, one death will remove three or four mutations from the population at one time.

In the interests of perspective, I must point out that sobering though these figures be, probably only a fraction of the population will clearly exhibit gross evidence of these mutations in any generation. Otherwise stated, geneticists believe that in each generation about 2 or 3 percent of the population exhibits defects with a simple genetic background, the frequency of these defects being maintained to a considerable extent by naturally occurring mutation. Now then, let us assume that for 30 generations after the exposure the population of the United States remains constant, so that each generation 40 million persons are born. This is obviously not going to be the case, but it makes our calculations simpler. Altogether in these 30 generations there will be 30×40,000,000 persons born, or 1,200,000,000. If, due to natural causes in no way related to the bombings, 2 to 3 percent show simply determined genetic defects, there will be for natural reasons, a total of 24 million to 36 million defective persons. Against this contrast the 240,000 to 38,400,000 added defective individuals we estimate will result from this radiation exposure. They will be someplace between 1 percent and over 61 percent of the total to be observed during that period. Such comparisons could be made for the other categories of defect we have mentioned.

There has been only one significant opportunity to study this problem in a human population to date, in Hiroshima and Nagasaki. Our observations there involved far fewer people and smaller doses than the current assumptions. There we saw no increase in defective individuals or early deaths, but a very probable change in the sex ratio. The full account of that study is a little long to insert in the record, but I do ask permission to insert a more recent paper, by Dr. W. J. Schull and myself, summarizing the findings regarding the sex ratio. This is a paper published recently in Science.

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RADIATION AND THE SEX RATIO IN MAN—SEX RATIO AMONG CHILDREN OF SURVIVORS OF ATOMIC BOMBINGS SUGGEST INDUCED SEX-LINKED LETHAL MUTATIONS

(By William J. Schull and James V. Neel) [1]

In species with an XX–XY type of chromosomal sex determination, such as man, the distribution to the offspring of radiation-induced, sex-linked mutations will differ according to the sex of the radiated parent. Furthermore, in the human species the nonhomologous nature of the X- and Y-chromosomes, couple with the genetic inertness of the Y, permits the more frequent manifestation of sex-linked recessive genes in the heterogametic sex—namely, the male. This difference in manifestation and distribution of sex-linked genes would lead us to expect a significant change in the sex ratio if human populations were sufficiently exposed to mutagenic factors such as X-rays, or the fallout from weapon testing. Specifically, if fathers alone were exposed, an increase in the frequency of male births would be expected because sex-linked lethal mutants induced by the exposure would be transmitted only to the exposed fathers' daughters. If mothers alone were exposed, a decrease in the frequency of male births would be expected because sex-linked recessive mutants would more frequently find expression in the sons rather than in the daughters of the exposed females.

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[1] The authors are on the staff of the department of human genetics at the University of Michigan Medical School, Ann Arbor.

If both parents were exposed, and if the effects of parental exposure were additive although not necessarily equal, we would expect a decrease in the frequency of male births; the change, however, would not be expected to be as pronounced as when mothers alone were exposed.

ASSUMPTIONS

Several assumptions are implicit in postulating the changes just mentioned, and it seems important to state explicitly, at the outset, these assumptions, with a brief justification for each. Firstly, it is assumed that although autosomal lethal or semilethal mutations which are sex-limited may occur, their net effect is not such as to obscure the different effects on the sex ratio of paternal versus maternal radiation. Clearly, were this not so, the deviations postulated could be altered in degree or direction depending upon the relative frequencies of male-limited or female-limited mutants, or both. In view of the current state of knowledge of radiation genetics, it seems appropriate to assume that the predominant change in the sex ratio will stem from sex-linked rather than sex-limited effects.

Secondly, it has been assumed that the effect on the sex ratio of genes in the Y-chromosome is negligible, and that there exist no homologous portions of the X- and Y-chromosomes. The reasonableness of the former is supported by the knowledge that there is known, at present, no single, well-documented case of holandric inheritance, although this form of genetic transmission should be easy to recognize (for a discussion of Y-borne inheritance, see Stern (*1*)). The legitimacy of the assumption that there is no homology between the X- and Y-chromosomes rests on the cytological work of Mathey (*2*) and Cachs (*3*).

TABLE 1.—*Summary of the findings of Kaplan (7) and of Macht and Lawrence (6) with regard to the frequency of male births following parental exposure to ionizing radiations*

Exposed parent	Estimated dose (r)	Total offspring of known sex born after radiation	Male	Female	p
	Kaplan, 1956				
Mother	50–200	407	200	207	0.4914
	Macht and Lawrence, 1955				
Father	Unknown	4,277	2,198	2,079	0.5139
None	Control	3,491	1,830	1,661	0.5242

Thirdly, and with reference to the exposure of both parents, it is assumed that sex-linked recessive mutants would outnumber sex-linked dominant mutations. The only animal for which data exist relevant to this assumption is *Drosophila melanogaster*, and here sex-linked recessives are estimated to be several times more common than sex-linked dominant mutants. In this connection, however, attention must be called to the evidence which suggests that sex-linked spontaneous mutation occurs more frequently in the human male than in the female (*4*, *5*). The possibility must be entertained that the same may hold true for sex-linked induced mutations. If this is, in fact, true, then maternal exposure may not lead to a relatively greater effect on the sex ratio than paternal exposure. The directions of deviation of the sex ratio would not of course be altered even if induced sex-linked mutations occurred more frequently in the male than in the female. One other assumption which has been made in the analysis of the data presented below is that the increase in gene mutations with increasing radiation is linear over the measurable range of exposures. The linearity of the response in gene mutations to dose of radiation is one of the cornerstones of radiation genetics, and rests on a literature far too extensive to review here. Suffice it to say that since linearity obtains in all organisms thus far studied, it seems improbable that a different situation would obtain in man.

STUDIES OF THE SEX RATIO

To date, four studies on man have reported information on the sex ratio among infants born subsequent to parental exposure to ionizing radiations. These are the observations of Macht and Lawrence (*6*) on the offspring of American radiologists; of Kaplan (*7*) on the pregnancies occurring to women following the use of x-ray therapy to correct an apparent sterility; of Turpin, Lejeune, and Rethore (*8*) on the sex of children born to French men and women receiving x-ray therapy for sciatic neuralgia and a variety of other complaints; and, lastly, of Neel and Schull (*9*) on pregnancy terminations to survivors of the atomic bombings of Hiroshima and Nagasaki. We present in Table 1 a summary of the findings of Kaplan and of Macht and Lawrence; in Table 2, the findings of Turpin, Lejeune, and Rethore; and in Tables 3 and 4, the findings of Neel and Schull. In the presentation of these data, we give, when it has been published, the author's estimate of the average exposure (or the range) sustained by the various groups of individuals. Let us be the first to recognize the tenuous nature of these estimates; however, since we shall be principally concerned with the direction of deviation of the sex ratio rather than the magnitude of the change, precise specification of the dose is less important, in a sense, than the proper ranking of the various exposure groups.

In a discussion of the data presented in Tables 1 to 4, one can deal rather briefly with the findings of Kaplan and of Macht and Lawrence (Table 1). In Kaplan's case, there does not exist a satisfactory unexposed control for his observations, nor have the data been presented in a fashion such that the proportion of male births could be regressed on different maternal exposures (generally Kaplan's cases received 200 roentgens, but some appear to have received less). In Macht and Lawrence's data, it is impossible to estimate the average exposure of radiologists in the United States as constrasted with physicians who are not radiologists. It is worth noting, however, that the direction of deviation in Kaplan's data would appear to be in keeping with genetic theory, for the frequency of male births is less than in the general population; this may not, however, be a meaningful comparison. The direction of deviation in Macht and Lawrence's data, on the other hand, is contrary to genetic theory; there are proportionately fewer, rather than more, males when the fathers were exposed.

TABLE 2.—*Summary of the findings of Turpin, Lejeune, and Rethore (8) with regard to the frequency of male births following parental exposure to ionizing radiations.*

Exposed parent [1]	Estimated dose (r)	Reproductive performance before exposure					Reproductive performance after exposure				
		Total matings	Total children of known sex	Male	Female	p	Total matings	Total children of known sex	Male	Female	p
ALL CASES											
Father (b)	Unknown	66	112	62	50	0.5536	52	96	42	54	0.4375
Father (C_1)	1295	284	465	242	223	0.5204	194	275	157	118	0.5709
Father (C_2)	1461	137	231	116	115	0.5022	95	130	68	62	0.5231
Mother	1360	154	236	130	106	0.5508	97	136	63	73	0.4632
ONLY CASES HAVING CHILDREN BEFORE AND AFTER EXPOSURE											
Father (C_1)	1295	92	150	79	71	0.5267	92	119	66	53	0.5546
Father (C_2)	1461	42	67	30	37	0.4478	42	51	27	24	0.5294
Mother	1360	45	61	37	24	0.6066	45	51	26	25	0.5098

[1] An explanation of the subdivisions of paternal exposure will be found in the text.

Turpin, Lejeune, and Rethore's observations (Table 2) warrant somewhat more extended discussion. These authors selected for study, from the radiotherapy files of all the hospitals in and around Paris, 4,428 individuals who had received radiotherapy between 1925 and 1952, a substantial majority having been treated between 1940 and 1952, and where the estimated skin dose was in excess of 300 roentgens. Two other restrictions were placed upon the cases to be selected—namely, the radiotherapy had to be for complaints of a noncancerous nature, and the exposed persons were to be adults less than 35 years of age, if female, and less than 40, if male. Repeated questionnaires were then sent to these individuals. In all, questionnaires were sent to 3,579 males, of whom 37.4 percent (1,334) responded, and 849 females, of whom 33.5 percent (284) responded. Turpin *et al* do not present data which would afford some indication of how representative the respondents were of the whole group queried. This is, of course, a problem of real concern in all questionnaire surveys, and especially in those surveys where only a minority of those queried bother to respond.

Be this as it may, the irradiated males were divided by these authors into three groups (a) 368 cases where the X-ray was delivered high up on the lumbar region, or to the thigh, (b) 180 cases where irradiation was to the pelvic area but with the gonads probably shielded, and (c) 786 cases where the subjects were irradiated in the pelvic area under conditions making protection of the gonads impossible. Turpin *et al.* present data on reproductive performance for groups (b) and (c), but not for group (a). In the analysis of their data, group (b) is rejected because of the uncertainty regarding the amount of radiation received by the group. The third group, (c), was further subdivided into individuals treated for "sciatic neuralgia" [517 cases (group c_1)], and for various other complaints [269 cases (group c_2)].

Turpin *et al.* use, as is apparent from Table 2, the reproductive performance of the exposed individuals prior to their exposure as the base of reference with which to compare reproductive performance after exposure. This procedure leads to a confounding of age and parity effects with those due to radiation. The importance of this confounding is difficult to assess. We know (i) that first-born children are more frequent males than children in subsequent birth ranks (*10*), and (ii) that the frequency of male births tend to decrease with advancing maternal or paternal age (*11*). It is not clear whether the correlation between birth rank and frequency of male births is due wholly or in part to the correlation between birth rank and parental age. Conceivably this confounding could, then, lead to an overestimation of maternal exposure effects and an underestimation of paternal effects.

TABLE 3.—*Summary of the findings in Japan with regard to the association of the frequency of male births and parental exposure. Only one parent exposed*

Father only exposed				Mother only exposed			
Total births	Male births	p	Estimated mean exposure (rep)	Total births	Male births	p	Estimated mean exposure (rep)
Neel and Schull, 1956 (1948–1953) (9), parents unrelated							
31,904	16,613	0.5207	0	31,904	16,613	0.5207	0
3,670	1,892	.5155	8	14,684	7,681	.5231	8
839	442	.5268	75	2,932	1,474	.5027	75
534	284	.5318	200	1,676	850	.5072	200
Neel and Schull, 1956 (1954–1955) (9), parents unrelated							
11,640	6,067	0.5212	0	11,640	6,067	0.5212	0
1,498	774	.5167	8	4,926	2,512	.5099	8
387	211	.5452	75	1,026	562	.5478	75
219	113	.5160	200	592	311	.5253	200
This article (1948–1953), parents related							
2,622	1,396	0.5324	0	2,622	1,396	0.5324	0
295	152	.5153	8	963	466	.4839	8
83	46	.5542	100	258	134	.5194	100

Table 4.—*Summary of the findings in Japan with regard to the association of the frequency of male births and parental exposure. Both parents exposed*

Total births	Male births	p	Estimated mean exposure (rep)	
			Mother	Father
Neel and Schull, 1956 (1948–53) (9), parents unrelated				
5,994	3,053	0.5093	8	8
658	337	.5122	8	75
422	225	.5332	8	200
703	354	.5036	75	8
615	319	.5187	75	75
192	94	.4896	75	200
318	165	.5189	200	8
145	72	.4966	200	75
145	71	.4896	200	200
Neel and Schull, 1956 (1954–55) (9), parents unrelated				
1,474	806	0.5468	8	8
220	129	.5864	8	75
174	101	.5805	8	200
212	111	.5236	75	8
107	53	.4953	75	75
66	35	.5303	75	200
89	48	.5393	200	8
43	20	.4651	200	75
33	18	.5455	200	200
This article (1948–53), parents related				
394	208	0.5279	8	8
69	38	.5507	8	100
54	29	.5370	100	8
43	21	.4884	100	100

The extent of this over- or underestimation is in part a matter of speculation; however, Ciocco (*10*) has found that the sex ratio among first born is 0.5153 and that the sex ratio among fifth or higher order births is 0.5124. This change would be the equivalent of approximately 50 rep of maternal exposure, judging from the Japanese data (see below). It is not our purpose to present a critique of the data of Turpin *et al.*, but merely to indicate that this study, like all of the others, including our own, suffers from several deficiencies. One must, therefore, exercise considerable caution in any interpretation of the data on the sex ratio. Be this as it may, it is interesting to observe that of the four comparisons afforded by all of the data presented by Turpin *et al.*, three are in the direction which one would expect on genetic grounds.

JAPANESE DATA

Before we turn to a description of the Japanese data, it is important that one rather important fundamental difference between the study in Japan and those previously mentioned be pointed out. The data of Kaplan, Macht and Lawrence, and Turpin *et al.* involve observations on individuals whose exposure was distributed over some interval in time. Thus Macht and Lawrence's observations are on persons whose total dose may be appreciable, but this dose was incurred at relatively low levels and over a considerable period of time. Kaplan's individuals received three exposures of 50, 75, and 75 roentgens, and the interval intervening between successive exposures was 7 days. Turpin *et al.* do not state that the individuals in their study received repeated exposures; however, if the practice of radiotherapy in France is similar to that in the United States, this is undoubtedly so. The observations from Hiroshima and Nagasaki, on the other hand, are on individuals who received but a single exposure.

In the past, this distinction would perhaps not have been considered important since the data from *Drosophila*, for example, suggest that the critical factor is the total dose and not the period of time over which this dose occurred. Recently.

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however, Russell (*12*) has presented data on the mouse which suggest that the effect of chronic irradiation for a given does and in terms of the frequency of the induction of specific locus mutations is less than the effect of acute irradiation. Russell states "Results obtained from an accumulated dose of 600 r given to spermatogonia at approximately 100 r/wk continuous irradiation show a much lower mutation rate than that obtained earlier with a 600 r acute dose of X-rays." The same also appears to be true at a total dose of 100 roentgens. If this finding is confirmed, and if the same phenomenon holds true in man, then there are reasons for believing that the Japanese data are not comparable to the studies in the United States and France.

The Japanese data concerning the effects of radiation on the sex ratio fall into three categories, as follows, two of which (i and ii) have been presented previously (*9*), but analyzed differently, one of which (iii) is presented here for the first time: (i) the sex ratio in infants born to *unrelated* parents in the years 1948–1953, these infants all examined by Japanese physicians; (ii) the sex ratio in infants born to *unrelated* parents in the years 1954–1955, sex reported by the parents but not verified by a physician examiner; (iii) the sex ratio in infants born to *related* parents in the years 1948–1953, these infants all examined by physician examiners. [A description of the background of these children will be found in Schull's report (*13*)].

Detailed presentation of the method of data collection and the bases for the dosage estimates for the parents will not be attempted here, since this material has been described by Neel and Schull (*9*) and Schull (*13*). The present method of analysis was an outgrowth of an effort to integrate the findings on the offspring of related parents with those previously reported on the pregnancy terminations of unrelated parents. In the analysis to follow, we have treated the data as if they were the results from three separate, but similarly oriented, experiences. The decision to do this was based upon two considerations. Firstly, the information collected in the years 1948–1953 involved direct observations by physicians on newly born infants, whereas the information obtained in 1954–1955 was based upon municipal birth records supplemented by a questionnaire to the parents. The two methods of collecting data would seem sufficiently different to justify maintaining a distinction between the two bodies of data which were collected. Secondly, within the years 1948–1953, the division of the data into observations on the offspring of related and unrelated parents seems appropriate in view of the frequently voiced belief that the increased homozygosity of the inbred child may make it a more sensitive indicator of genetic damage, and direct combination of these data was not feasible because of the dissimilarity in the frequency of consanguineous marriages in the various exposure classes. Let us turn now to a brief description of how the data have been analyzed, and a presentation of the results which were obtained.

As we have indicated, we have, in effect, three experiences, and the information with respect to each of these three experiences can be further subdivided into three parts—namely, pregnancies where the mother was exposed but the father was not, where the father was exposed but the mother was not, and where both parents were exposed. Within each of these nine "experience-exposed parent(s)" groups, there exist three or more dosage levels. Thus it is possible to fit nine linear regressions of the frequency of male births on the dose of radiation received by the parent(s). Six of these regressions will be of the form

$$E(p_i)=\bar{p}+b(d_i-\bar{d}),$$

where $E(p_i)$ is the expected proportion of males in the i^{th} exposure class, $\bar{p}$ is the mean proportion of males, d_i is the dose in the i^{th} exposure class, $\bar{d}$ is the average dose, and b is the regression coefficient. Three of the regressions will be of the form

$$E(p_{ij})=\bar{p}+b_1(F_i-\bar{F})+b_2(M_j-\bar{M}),$$

where b_1 and b_2 are now partial regression coefficients, F_i and M_j are, respectively, the doses in the i^{th} paternal and j^{th} maternal exposure groups, $\bar{F}$ and $\bar{M}$ are the mean paternal and maternal exposures, and $\bar{p}$ is, again, the mean proportion of male births. The regressions which were, in fact, fitted were weighted to allow for the differences in the numbers of observations at the various exposure levels. The weights which were used were the reciprocals of the variances (the information) of the proportions of males at the different dosage

levels. The final weights were obtained by iteration, starting with the observed proportions as trial values. The intercepts and regression coefficients which were obtained are presented in table 5. Several comments on these values are in order.

(1) It should be noted that no less than 11 of the 12 regression coefficients are of the sign anticipated by genetic theory—that is to say, the deviation is in the direction anticipated if sex-linked mutations have been induced by the exposure. The one nonconforming coefficient is that for mothers unrelated, 1954–55. The prior probability that 11 or more of 12 regression coefficients will have signs in keeping with genetic theory, if the signs of these regression coefficients are, in fact, equiprobable, is approximately 1 in 341. Clearly the array of signs is significant.

(2) Only one of the regression coefficients can be shown to be significantly different from zero, at the 5-percent level of significance, and, unfortunately none of the common regression coefficients for mothers only exposed, fathers only exposed, or both parents exposed differs significantly from zero. It should be mentioned here that substantially the same results are obtained if the arc sin transformation is used.

(3) It will be noted from table 3 that certain observations—namely, those where both parents were unexposed—occur more than once. This, of course, implies that the regression coefficient for "fathers only exposed, 1954–55," say, is not wholly independent of the regression coefficient for "mothers only exposed, 1954–55." It may, therefore, be argued that we are not, in fact, dealing with 12 independent regression coefficients since some data are scored twice. This difficulty can be avoided, at the expense of some observations, by omitting entirely the observations on both parents unexposed, and basing the regression coefficients on only those data where the "exposed" parent experienced some irradiation. When this is done, we find that 10 of these 12 estimates have the signs one would expect from genetic theory under these circumstances. A simple sign test reveals that approximately 2 times in 100 we would expect this distribution of signs, or one favoring genetic theory even more if, in fact, the null hypothesis were true.

ANALYSIS

The findings in the Japanese data pose two very interesting and important questions. (i) How much confidence can we place in these findings as evidence of radiation-induced genetic damage? (ii) If the changes in the sex ratio are, in fact, manifestations of genetic damage, why do we not find evidence for a radiation-induced change in the frequency of congenital malformations or one of the other attributes of a pregnancy termination? In this connection, it should be stated that an analysis of radiation effects in the consanguineous material with respect to malformation frequency and frequency of stillbirths and neonatal deaths, to be presented in detail elsewhere, fails to yield results comparable to those regarding sex ratio, in their negativity confirming the findings reported earlier for the children born to unrelated parents (*9*). Clearly a categorical answer to either of these questions is impossible; however, certain observations seem pertinent to any answer which one may arrive at.

With respect to the first of these two questions, we have indicated elsewhere (*9*) the interpretive difficulties which arise when one begins to select, in the Japanese data, specific cells or groups of cells on which to base comparisons. The present approach would, however, seem to avoid many of these difficulties since (i) all of the data are used, and (ii) the division of the data was based upon a priori considerations regarding parental exposure, relationship, and method of data collection alone, and did not involve value judgments regarding the extent to which one portion of data, collected at one time and in one manner, was *in pari materia* with another collected at the same time and in the same manner.

TABLE 5.—*Means and regression coefficients obtained by fitting a weighted linear regression of the proportion of male births to average group exposure in the Japanese data. The values in parentheses are those obtained when unexposed parents are rejected.*

References: Neel and Schull, 1956 (*9*); Schull and neel, 1958 (this article)	Father only exposed		Mother only exposed		Both parents exposed			
					Father		Mother	
	$\bar{p}$	b [1]	$\bar{p}$	b	$\bar{p}$	b	$\bar{p}$	b
1948–53:								
Unrelated parents	0.5202	0.0058 (.0094)	0.5213	[2] −0.0101 (−.0111)	0.5102	0.0039	0.5102	−0.0037
Related parents	.5307	.0188 (.0423)	.5204	−.0116 (.0386)	.5310	.0024	.5310	−.0179
1954–55:								
Unrelated parents	.5211	.0039 (.0047)	.5186	.0090 (.0141)	.5464	.0137	.5464	−.0269
Common regression coefficients	....	.0056	....	−.0080	....	.0036	....	−.0042

[1] Regression coefficients are given as increase or decrease in proportion or male births per 100 rep. [2] Significant at the 5 percent level.

It must be pointed out, however, that the sex ratio, as a variable, leaves much to be desired, the elegant genetic argument which can be advanced for expecting changes in the sex ratio consequent to parental exposure notwithstanding. Any number of factors—for example, maternal age, paternal age, parity, war, and so forth—seem capable of altering the sex ratio, and though these effects are, in general, small, adequate explanation for the peculiar variations which occur due to these factors has not been advanced. Perhaps the greatest recommendation for accepting the observations with regard to the sex ratio as a manifestation of a real effect of parental exposure is the consistency of the findings. It is true, however, that one does not find within the Japanese data other evidence of sex-linked lethal genes which might logically be expected, such as an increase in the difference in frequency between inviable males and inviable females as maternal exposure increases. The significance of this absence of what might be termed "secondary effects" is not readily appraised since (i) the direct effect on the sex ratio is itself small and (ii) the sex difference in viability has been measured only for the period from approximately the 21st week of gestation onward. Thus, sex-linked lethal mutants leading to gametic death or to the early death of the zygote would not come within our ken.

A further possible recommendation for accepting the results as real is the apparent "reasonableness" of the change. The following rather simple calculation illustrates this: The average number of induced sex-linked lethal mutants at any given dose of radiation is equal to the product of the number of genetic loci at risk, the probability of inducing a mutant per unit dose, and the dose received. If we accept 0.0060 as the best estimate of the change in the sex ratio following 100 rep of maternal irradiation, and if we assume that the number of "targets" —that is, sex-linked lethal producing genetic loci on one X-chromosome—lies between 250 and 2,500, then we find that the probability of a sex-linked lethal mutation per rep lies in the interval 2.4×10^{-7} and 2.4×10^{-8}. Current genetic thinking would tend to suggest that the number of loci at risk is rather nearer 250 than 2,500, and hence that the sensitivity of human genes would be more likely to be of the order of 2.4×10^{-7}, a figure which agrees well with the findings for the only other mammal studied thus far, the mouse (*14*), but which suggests a significantly greater sensitivity than that observed in *Drosophila*.

With respect to the second of the two questions raised above, concerning the implications for the validity of the sex-ratio findings of the failure to demonstrate parallel changes with regard to the frequency of malformations or stillbirths or neonatal deaths, it should be pointed out that Neel (*15*) has recently suggested, on the basis of an analysis of certain aspects of the Japanese data and a comparison of the findings with those available for Caucasian populations, that a significant fraction of congenital malformations may be the segregants from complex homeostatic genetic systems. If this viewpoint is correct, then it follows that induced mutations at loci involved in these homeostatic systems, while ultimately resulting in an increase in malformation frequency, would not be expected to bear the same simple and immediate relationship to malformation frequency as sex-linked lethal mutations do to the sex ratio. It may well be, then, that no conflict of evidence is involved in the failure to demonstrate an effect of radiation exposure on malformation frequency in the first postbomb generation.

SUMMARY

An analysis of new data concerning the sex of children born to the survivors of the atomic bombings of Hiroshima and Nagasaki, together with a reanalysis of the data previously presented by Neel and Schull (*9*), reveals significant changes in the sex ratio of these children, changes in the direction to be expected if exposure had resulted in the induction of sex-linked lethal mutations (*16*).

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Dr. NEEL. This change in the sex ratio was presumably brought about by the early death of some developing embryos. On the basis of the Japanese experience, it appears unlikely that the number of obviously defective persons resulting from a radiation exposure such as we are now discussing will exceed my high estimate.

I would hesitate to be any more definite than I have been thus far, since I feel we have had enough of calculations that specifiy just how many defective children will result from a given exposure, carefully guarded though these calculations be.

To deprive the picture on the worldwide scale, obviously we simply multiply the U.S. experience by some appropriate factor.

The question inevitably arises: Can the human race survive this experience, or will this number of mutations so lower the fitness of our species that we can no longer maintain ourselves? It is my opinion, which cannot be backed up by any rigorous calculation, that we can survive, but at the cost we have just discussed. To a rough approximation, between 500 and 1,000 r. units average exposure per person, not acute but cumulative, would result in mutations about equal in number to the deleterious genes the human species already possesses. I believe the species could stand such an increase for a single generation, although, obviously, at a considerable cost.

One final remark: No one regrets more than I the vagueness of this testimony. The scientific study of the genetics of man on a significant scale has scarcely begun. In time it will undoubtedly be possible to obtain a much clearer picture of these genetic effects than I have given you today, but this will require a far greater expenditure of research effort than has occurred in the past.

Representative HOLIFIELD. Thank you very much for your testimony, sir. One of the things that has impressed me, in the testimony we have had from you and from other witnesses, has been the fact that you have been frank and honest in giving your professional opinion, particularly in the field of the unknown where you are making estimates which are based on your best experience and best judgment, but you do not take a dogmatic position as being the last answer for the problem involved.

Would it be safe to say that in this particular field of mutations, the factors of the unknown are so great that if a person makes a dog-

matic assertion in this field he is going beyond the bounds of scientifically proved data?

Dr. NEEL. In my opinion that is a correct statement.

Representative HOLIFIELD. So anyone who gets up and says dogmatically that X amount of people will have leukemia or X amount of people will have anemia, and there will be X amount of abnormality in births is drawing upon their own theory rather than upon any way of establishing it as a proven fact. Is this true?

Dr. NEEL. Yes, sir.

Representative HOLIFIELD. This does not mean that the opinions of scientists are not valuable, because we have to accept the best judgment and the best knowledge in many fields. This, of course, is why this committee is trying to bring together the most reputable testimony we can get from professional witnesses who have standing in their respective fields, and why we are going to subject them always to panel discussions to allow anyone who wishes to challenge their statements to do so.

Congressman Hosmer.

Representative HOSMER. Dr. Neel, I would like to try to get this table of yours on the 30 generation effect of mutations in terms of each of those generations. I think perhaps we can understand it a little better if we do that. You have a line there for obviously defective persons and the low estimates are 240,000–960,000 for the 30 generations. Is that what that means?

Dr. NEEL. Yes, sir.

Representative HOSMER. If you take the low, low estimate and divide by 30, you would come up with a number for a particular generation, assuming that effects are fairly equally spread among each generation. I think after the first generation they do come out fairly equal.

Dr. NEEL. Assuming equal distribution over the 30 generations that would give you the number of persons in each generation.

Representative HOSMER. In the case of the low, low that would be 8,000 in the first generation or in any one generation.

Dr. NEEL. Yes, sir.

Representative HOSMER. Out of 40 million births.

Dr. NEEL. Yes, sir.

Representative HOSMER. Using the figures you used.

Dr. NEEL. Yes, sir.

Representative HOSMER. Then we will take this high, high, which is 38,400,000, and I have divided that by 30 and I think the answer is 1,280,000 defective persons in that generation.

Dr. NEEL. Yes, sir.

Representative HOSMER. In any generation I believe your testimony says there will be 2 to 3 percent of such births anyway.

Dr. NEEL. Yes.

Representative HOSMER. Just using the high figure, in any event of the 40 million births, without any consideration of radiation, we can expect 1,200,000 of them to be of such defect that it would amount to blindness, imbecility, and so forth. On your low, low estimate, raising that by 8,000, although it means a lot to the 8,000 involved, statistically it is a minor increase.

Dr. NEEL. About 1 percent.

Representative HOSMER. It would be an increase of 1,200,000 to 1,280,000, much less than 1 percent.

Dr. NEEL. I calculate it would be roughly one-half of 1 percent on the low, low estimate and on the high estimate approximately 50 percent of all defects.

Representative HOSMER. On the basis of each generation, using this formula that I have developed here, I wish you would calculate that out. Your 1,280,000 which is the correct figure for that high, high, has a percentage factor of 40 million, which added to your normal, would raise your obviously defective births from three to somewhere between five and six.

Dr. NEEL. If we take the figure of 2 percent defect in the population already, 2 percent of 40 million would be 800,000. You have just supplied the figure of 8,000 on my low estimate additional defective which would be 1 percent.

Representative HOSMER. Could you make a table along that line to submit to us?

Dr. NEEL. In terms of the percentage effect in each generation?

Representative HOSMER. Yes, and the percentage in numbers in each generation.

Dr. NEEL. I would do that gladly.

(The material referred to follows:)

Assume equal distribution of the manifestations of the induced mutations over the 30-generation period used for purposes of calculation. Assume constant population of 40 million persons each generation, with 2 to 3 percent, or 800,000 to 1,200,000 persons, exhibiting defect each generation due to "natural" genetic causes. On a per-generation basis, the low estimate of table 2 is 8,000 to 32,000 mutations resulting in obviously defective persons, and the high, 320,000 to 1,280,000 mutations. On a percentage basis, equating for ease of calculation mutations to persons, the low estimate of the percentage of genetically defective persons due to induced mutuation among the new total (natural + induced) is between

$$\frac{8{,}000}{1{,}200{,}000+8{,}000}$$

and

$$\frac{8{,}000}{800{,}000+8{,}000}$$

or 0.7—1.0%

and the high estimate between

$$\frac{1{,}280{,}000}{1{,}200{,}000+1{,}280{,}000} \text{ and } \frac{1{,}280{,}000}{800{,}000+1{,}280{,}000}$$

or 51.6—61.5%.

If one chooses to frame this increase in terms of total births in the population, then the percentage of defective individuals due to the bombings among all births is between

$$\frac{8{,}000}{40{,}000{,}000} \text{ and } \frac{1{,}280{,}000}{40{,}000{,}000}$$

or .02—3.2%.

Representative HOSMER. I think it gives us something that we can conceive. We can't conceive of 30 generations but we can conceive one generation of 40 million people.

Representative HOLIFIELD. Could I ask if the first generation would be based on an equal division between 30 generations? Of course, there would be a factor of declining rate in the 30 generations.

Dr. NEEL. The exact pattern in which these mutations would manifest themselves is not clear, but in general we would postulate that the first generation would show a larger effect than any other, because of the action of the dominant factors. Then in about three or four generations the recessive factors would begin to manifest themselves. They would rise to a peak in perhaps 15 or 20 generations, and then fall off. I believe Dr. Crow used the figure of 6 percent of the manifestations in the first generation.

Representative HOLIFIELD. In making this calculation you have assumed that each one of these mutations are effective in embryo.

Dr. NEEL. Yes, the death of one person may remove three or four different mutations.

Representative HOLIFIELD. From other causes, for instance. The death of all people radiated before the age would necessarily affect it.

Dr. NEEL. Yes. What I am attempting to say is that by chance one individual might receive four different mutant genes which occurred as a result of the radiation. If he died at an early age, his early death would remove from the population four mutations at one time.

Representative HOLIFIELD. The whole line for the next 30 generations.

Dr. NEEL. Yes, sir.

Representative HOLIFIELD. Thank you very much for your testimony.

Now we are going to ask the panel on biological effects to come forward. Those people who will participate are Dr. Paul C. Tompkins, Naval Radiological Defense Laboratory; Dr. Robert R. Newell, NRDL; Dr. Gordon Dunning, U.S. AEC; Dr. Hardin Jones, Donner Laboratory; Dr. Payne S. Harris, Los Alamos Scientific Laboratory; Col. J. E. Pickering, School of Aviation Medicine; Dr. James V. Neel, University of Michigan; Lt. Col. Gerald McDonnel, Surgeon General's Office, DOA; Dr. William T. Ham, Jr., Medical College of Virginia.

Most of these gentlemen have appeared before us already as witnesses, and some have not. The hearings up to the present time have considered the physical radiation and biological effects resulting from the type of hypothetical nuclear attack set up by the committee. A previous panel has discussed the physical and radiation effects which showed that, one, local fallout is capable of depositing lethal quantities of radioactive material many miles from the point of detonation; two, this material is deposited nonuniformly; three, the radiation from worldwide fallout deposition is from 10 to 20 times the worldwide fallout of tests conducted up to the present time. It was stated that these quantities would not threaten the survival of countries not subjected to attack.

We will now convene the panel to consider the relative importance and implications of the biological effects of radiation under conditions of nuclear war. The committee, I will say to the members of the panel, is more interested in receiving the panel's comments concerning lethal dose rates, and the effects of protracted radiation exposure. We do not mean to limit you to these subjects.

Dr. Paul Tompkins, will you please lead off and then gentlemen, hold up your hands for recognition.

PANEL ON BIOLOGICAL EFFECTS

Participants: Dr. Paul C. Tompkins, Naval Radiological Defense Laboratory; Dr. Robert R. Newell, NRDL; Dr. Gordon Dunning U.S. AEC; Dr. Hardin Jones, Donner Laboratory; Dr. Payne S. Harris, Los Alamos Scientific Laboratory; Col. J. E. Pickering, School of Aviation Medicine; Dr. James V. Neel, University of Michigan; Lt. Col. (MD) Gerald M. McDonnel, Surgeon General's Office, DOA; Dr. William T. Ham, Jr., Medical College of Virginia.

Dr. TOMPKINS. Mr. Chairman, I think the bulk of the testimony involving biological effects of radiation has emphasized two things. First of all, rather massive doses of radiation can be received in a short time with deleterious effects following consecutively over a period of time after that, and terminating eventually in death. The time of death, of course, depends on the initial level of the radiation.

We have also seen in our physical descriptions of the fallout fields that much of the radiation to which the population will be exposed will be protracted in time. The testimony has indicated that the biological effects due to these two classes of exposure are different enough so that I think it would be well for the panel to consider the magnitude of the differences, and the significance of the difference insofar as evaluating the results of this kind of an exercise is concerned. However, there has also been put into the testimony in these hearings some discussions as to the numerical value of the reference point for biological hazards, commonly known as the midlethal dose, or the LD–50. This has been known for years as a number equivalent to 450 roentgens.

Evidence was presented at these hearings that would indicate the potentiality that this should be revised to something like 700. I think it would be well to evaluate the significance of such a revision, and does it really change the picture very much insofar as the results on the people of the United States are concerned. I would suggest that we perhaps start off with Dr. Harris.

Representative HOLIFIELD. Dr. Harris, as you know, we have had a new formula put in. A lethal dose rate has usually been considered to be 450 roentgens for 50 percent of our population. We have some new figures, as you know, of 700 roentgens, and possibly 700 roentgens plus. So you might lead off.

Dr. HARRIS. I am apparently the culprit in this. As I pointed out in my prepared testimony, in actuality the LD–50, whether it be 450 roentgens or rad or 700 rad, does not mean much when one is looking at the acute effects of weapon radiation. I only pointed out that evidence that I had available, and evidence that I had used, indicated that the LD–50 was higher for the acute end point of death as far as I could see it.

I am glad this question came up, for several reasons. One is that I predicated in my testimony that the information or data that I used was on humans and was suspect and showed its maximum uncertainty in the actual dose delivered. This, I think, is important because you have heard subsequent testimony by various others who have used and applied doses to essentially the same populations that I did.

I don't know the source of the dose, but if they happened to use mine, the uncertainty holds for such things as the decrease in lifespan per unit dose as applied to the Japanese. The uncertainty in this dose

at the present time is such that I would not guarantee—this is applied to the Japanese only—that an LD–50 for humans would be accurate to greater than 75 percent. In other words, I apply a plus or minus 25 percent error in an extremely restricted population. If one does that, the limits of my LD–50 computation are in the neighborhood of 550 to approximately 850 or 900 rad.

The dose in this case is considered to be air dose, measured at the position of the individual. The number, 450 rad, which has been used so long, has an experimental basis in studies on large animals in which the dosimetry was good to excellent. Here the main uncertainty probably lies in the extrapolation from the large animal to man and some semantic difficulty with the meaning of the dose used in each case.

I have had many discussions with individuals about this subject, and although we are still somewhat apart in our estimates of LD 50, I again want to emphasize that in the case being considered here I am sure that neither myself nor others with whom I have had these discussions disagree in the overall picture. It turns out to be that this particular point, so convenient for laboratory work and so convenient for medical statistics, is not what we want as far as results to people are concerned under the conditions cited in this exercise.

Representative HOLIFIELD. I think you pretty well stated your position.

Dr. HARRIS. Yes, sir. I would just like at this time, if I might, to introduce, I hope not too bad a rebuttal, by one of my colleagues with whom I have been associated in this field for many years, Dr. Victor Bond, of Brookhaven National Laboratory.

Representative HOLIFIELD. We will be glad to hear from him. By the fact that you have introduced him you don't mean to say that you have put up a strawman to knock down.

Dr. HARRIS. No, sir.

Representative HOLIFIELD. You may proceed, Doctor.

Dr. BOND. Thank you very much, Dr. Harris.

As Dr. Harris has indicated we have had discussions on this subject before, and are somewhat at variance in our outlook on the subject. I can't agree more with Dr. Harris that perhaps the LD 50 really is not what we want to look at as far as human beings are concerned. I would like to come back to that in a moment.

I would like to say at the outset I don't know what the LD 50 for humans is. I don't think anybody else does. Dr. Harris has presented data from one source, and he has indicated the limits of error from the source he obtained, and I am not in a position to evaluate how good those are. I think it is only fair in this discussion to present another side of the picture that might give different results. There are other sources of data from which we can arrive at some sort of estimate of the LD 50 although, as I say, we do not know what the LD 50 is for man and it has never been determined.

Another is the Marshallese data. Another source of data is the human beings that have been exposed to radiation for radiotherapy in hospitals and the third one is large animal data.

Representative HOLIFIELD. Could I stop you just a minute there, and take those in line?

Dr. BOND. Yes, sir.

Representative HOLIFIELD. The first group that was exposed was the Marshallese?

Dr. BOND. Yes.

Representative HOLIFIELD. Are the scientists fairly well agreed upon the rate of exposure which they had?

Dr. BOND. I will answer that very frankly. No, sir. There is a very large uncertainty in that.

Representative HOLIFIELD. For purposes of extrapolation you are accepting 175-roentgen exposure.

Dr. BOND. Yes, sir.

Representative HOLIFIELD. And you are going back from the measurements that were taken at the time our forces arrived at the islands or at the time you had instruments on the islands?

Dr. BOND. No, sir. There were no instruments on the island. These doses were derived from estimates of instrument readings approximately a week following the detonation.

Representative HOLIFIELD. And you extrapolated back and used the average rate of decay?

Dr. BOND. Yes, sir.

Representative HOLIFIELD. Let us take the second group we spoke of.

Dr. BOND. There is a large uncertainty in that. There is a large uncertainty in the Japanese data, too.

Representative HOLIFIELD. In the Japanese case there is an even larger uncertainty, isn't there, because we had no one in to measure until much later?

Dr. BOND. Of course, there were no dosimeters there. That is based on calculations with errors in the calculation. There were no measurements of dose in the Japanese, nor were there in the Marshellese, so both are based on calculations.

Representative HOLIFIELD. What is the nature of the calculations in the Japanese case? Was it as good as the Marshallese case?

Dr. BOND. It is very difficult, sir. This is not subject to usual statistical analysis. This is almost your guess versus my guess.

Representative HOLIFIELD. My guess is no good.

Dr. BOND. Then it is someone else's guess versus my guess. I can put a sigma or standard deviation on this sort of thing.

Representative HOLIFIELD. Let us take the third dose, the exposures of individuals to incidents in our atomic laboratories.

Dr. BOND. I certainly appreciate your approach to this problem. This is very good. In the third situation, the dosimetry as Dr. Harris indicated is very good as dosimetry goes. The difficulty here is that we are dealing with diseased human beings but we are dealing with human beings.

Representative HOLIFIELD. In the case of the Los Alamos Laboratory incident, Dr. Graves being one of the injured people who lived, do we have any accurate readings on the exposure that the two men had who died?

Dr. BOND. This is a very complicated situation. The dosimetry there was done in the best manner possible but there are great uncertainties in this. Furthermore, it is complicated by the fact that it was mixed radiation of various types and various energy radiations and furthermore it was essentially partial body as well as whole body irradiation. In other words, portions of the body received a very large dose. So it is very difficult to apply the data from accidents to

the problem, although I must say in the recent accident at Oak Ridge, the dosimetry done by Dr. Hurst, and his group, is the best yet that has come out of an accident of this kind.

Representative HOLIFIELD. For the record, we are speaking of the one where Dr. Slotin died.

Dr. BOND. Yes, sir. The second one I am referring to is June 16 of last year at Oak Ridge.

Representative HOLIFIELD. You will retain the microphone. Did you wish to comment on this phase of it, Dr. Newell?

Dr. NEWELL. I do very much, because I feel this question of the uncertain value of LD 50 to man is not very rewarding for the use of your committee. I feel quite sure. The idea is that in an uncertain future we have no notion how well the enemy will control himself. We don't know whether we are going to be faced with a large attempt or a limited attempt. We don't know how good his delivery will be. We don't know how good his aim will be. We have no notion whether he will manage to hit our population centers or whether he will largely miss them. In view of the very great uncertainties of this nuclear war which we are imagining, it seems to me that the uncertainty in regard to the LD 50 is hardly pertinent.

Representative HOLIFIELD. Dr. Newell, we are not getting into the problems of delivery or the problems of attack. We are getting to the basis of the argument.

Dr. NEWELL. There are more important things to spend the time of the committee on than the precise value of the LD 50. In a future which looks as though there is going to be a very large diminution in population and when we are anticipating that the damage from the nuclear attack is going to be distributed over many generations in the future, and the uncertainty whether a survival of 20 million or 50 million——

Representative HOLIFIELD. I am sorry you are not speaking to the point at issue. The Chair will have to ask you to dispose of this thing in a logical manner. We can get to other subjects later. Proceed, Dr. Bond.

Dr. BOND. Thank you, Mr. Chairman. I think both Harris and I agreed at the start, the LD 50 may not be what we really wish.

To continue the point, I believe we completed reactor accidents, is that correct? Were there any further questions with regard to the data from reactor accidents?

Representative HOLIFIELD. No, I wanted to establish for the record the nature of these experiments or these assumptions which Dr. Harris had used as the basis for his arriving at the figure of 700 and 900 on the LD rate. The other type of experiments are on animals. I suppose you want to get to those.

Dr. BOND. If I may say just a word about the individuals exposed as far as radiotherapy is concerned, these individuals received whole body radiation. The indications here are so far without supporting therapy—here we have to define LD 50. An individual who has not received replacement therapy of platelets or transfusion and this sort of thing, individuals get into serious trouble when they have of the order of 200 roentgens of whole body radiation. These are sick patients again. These are patients who have a serious disease. But the bone marrow is believed to be in good shape.

With regard to animals, dosimetry is very good but this includes extrapolation from animals to man. May I make the point that in general the LD 50 for small animals is relatively high, that is, of the order of 500, 600, 700, 800 roentgens. Again it depends a great deal on how you express "dose," as Dr. Harris pointed out. The LD 50 for large animals, this includes dogs, pigs, goats, in general is small, of the order of 300 or less roentgens. So if we include man as a large animal, this would argue for a lower LD 50. I don't know what the LD 50 is. I merely indicate these arguments for a lower LD 50 and do not feel on the basis of the evidence available it is justified to raise the accepted value.

I do not wish to have it lowered. Really, I don't think is should be raised. If you wish to speak as of whether an LD 50 is appropriate to discuss, if that is what we really want, I would like to speak on that, also.

Representative BATES. Doctor, did you have sufficient dosimetry in your therapy cases to give you a sigma factor?

Dr. BOND. Sigma on the dosimetry, yes. It is not exactly a sigma, but your accuracy is determined by the instruments and is certainly within plus or minus 10 percent, and very likely plus or minus 3 percent.

Representative BATES. Three sigmas is pretty good.

Dr. BOND. These are ranges really. This is not a sigma.

Representative BATES. I thought you used the word "sigma" originally, and I thought you were talking statistically.

Dr. BOND. Yes.

Representative BATES. That is about 96, 95 factor, isn't it?

Dr. BOND. Yes, sir. Depending on the precise conditions, but under practically all conditions of the laboratory three signals would be within 10 percent accuracy, and most of it is much better than that.

Representative BATES. That reduces the error of probability considerably.

Dr. BOND. In the dosimetry. Then you have to bring in the factor that these are diseased individuals and do not necessarily represent a healthy young adult. In all of these instances you have advantages and disadvantages. I see no reason to pick out one and take this as the single criterion.

Representative HOLIFIELD. Is there any comment on this by any other member of the panel? Dr. Hurst?

Dr. HURST. I would like to make some comments at this point on dosimetry since we have hit on that subject and this happens to be the field of my specialty at Oak Ridge.

First of all, it has been recognized on many occasions at these hearings that LD 50 values and many other values for humans are not correlated very well with the radiation dose. I would like to make two types of comments on this.

The Health Physics Division at Oak Ridge is working on two series of human exposures where we hope eventually one will be able to correlate medical effects in man very carefully with radiation dose. The first of these was referred to in my testimony on Monday, the first day of these hearings, and that was the Japanese program, done in collaboration with the Atomic Bomb Casualty Commission and the National Research Council. The dosimetry group at Oak

Ridge is in charge of determining the dose received by the individuals at Hiroshima and Nagasaki. In my presentation I showed that we have essentially all of the basic input data we need on basic radiation physics. We even know the details about th angular distribution of incoming radiation. We know how much Japanese-type houses will attenuate this radiation. But the main uncertainty in these values lies in the dose outside the houses. We have the variation with distance and we know how much the houses attenuate, but we don't know the actual magnitude of the air dose, and we don't know how to scale this quantity.

As I mentioned, the only likely way to reduce this uncertainty in the air dose would be to reconstruct the Hiroshima and Nagasaki weapons. At the present time there is an uncertainty almost as much as a factor of two in these dose quantities.

We are also looking into the problems of dosimetry associated with people who become involved in radiation accidents. It is almost certain that these accidents are unfortunately going to continue to happen in the future, and we are making efforts to have the correct kind of dosimetry techniques worked out in advance so that when people are in these accidents, we will be able to correlate the medical effects on these people with doses. We are working very closely with the Atomic Energy Commission Division of Biology and Medicines on this matter, and they are trying to encourage the implementation of fixed dosimeter stations that will be put around the various areas where these criticality accidents are thought to be possible.

With the information obtained from these fixed dose stations, and with the data on the amount of sodium 24 induced in the particular individual, doses can be assigned, and they can be assigned on an individual basis. So we hope that in a very few years that if people are unfortunate enough to be in radiation accidents that the correlation of dose to medical effects will become much better.

Representative HOLIFIELD. Dr. Dunning.

Dr. DUNNING. I think in our discussion of LD 50 or any other LD value we ought to keep clear whether we are talking about the young healthy adult or the mixed population. There might be a difference. Also for the record, there were readings taken at Rongelop on D plus two or two days after the fallout. There may be some question as to how valid they are, but that can be said of most any of these measurements.

Dr. BOND. Those readings were taken with instruments that were not properly calibrated. We went into that carefully and did not use those in the calculation of dose. That is why we took the readings taken at a later time, even though longer time meant a greater uncertainty in extrapolating back.

Representative HOLIFIELD. Dr. Tompkins.

Dr. TOMPKINS. Dr. Bond made a comment I was going to make. Some of our people made the readings in question, and we saw to it that they did not use them.

Representative HOLIFIELD. In other words, you can't measure with an elastic tapeline.

Dr. TOMPKINS. Yes, sir. There are a couple of points I would like to make in connection with the subject, but not on this particular item, if I may, Mr. Holifield.

In the testimony, and most of my discussions I have not heard very much disagreement with the point of view that a thousand roentgens could be considered essentially a lethal dose; 100 percent of the people getting this magnitude of radiation would be expected to die.

Representative DURHAM. Where are you getting most of your information from? From the animals or from the human beings? You seem to be in disagreement here on the human beings, but aren't you more accurate on the animals?

Dr. TOMPKINS. Yes, sir. I think the actual numbers on animals are more accurate than on humans. But then one has to extrapolate from animals to human beings.

Representative DURHAM. We have been doing that in the medical field for 100 years.

Dr. TOMPKINS. Yes, sir.

Representative DURHAM. So why is it different? We do it in digitalis.

Dr. TOMPKINS. I don't think the extrapolation is any more inaccurate here than it has been for a hundred years in the medical field. The extrapolation is not precise. This is the point I would like to make. This is not a precise number. It is an approximation. It is a good range. As the two gentlemen have pointed out, in terms of our state of knowledge, one number is about as good as another in terms of what it really implies.

Representative DURHAM. Unless we happen to have a catastrophe or war or something or other, what few accidents have happened and what happened in Japan, we have a limited field with human beings for a long time to come. It is all right to work with them, I think, but we don't want to expose them unless you have to in case of an accident.

Dr. TOMPKINS. Yes, sir.

Representative DURHAM. It seems to me that this work will have to be done in animals such as it has been done for many years.

Dr. TOMPKINS. I don't think there is any disagreement on that point.

Representative HOLIFIELD. Let us go from the differences in concept of the exact amount of roentgens needed for LD 50 to the point of what effect would this difference in opinion have upon this exercise as far as affecting the population is concerned. Is it the opinion of the panel that this would have a substantial effect or would it have a small effect? Dr. Jones?

Dr. JONES. If we use the higher value of the LD 50, which I have not used, it would mean that the survivors would, on the average, have a higher total body radiation and a greater lifespan reduction. So, you see, the effects tend to cancel out; fewer would die promptly, leaving more survivors, but those survivors are going to be in poorer health. The same thing I am sure can be said by Dr. Neel for the genetic effects.

Dr. NEEL. Yes, it would increase the genetically effective radiation exposure if the LD 50 is substantially greater than our current estimate.

Dr. JONES. Uncertainty by a factor of two in measuring radiation doses is quite common at the present time. Even in physical systems where things are pinned down more exactly than in biological systems,

dosimetry is not easy. In recent times we have found in our own university in a great physics laboratory, that the physicists unknowingly can be off by a very great factor in dosimetry. We biologists were troubled by this situation. We found that the physical dosimetry was off and there was no good explanation why it was off. It was not a question of arithmetic, but a question of very subtle differences in the structure of the measuring system. If we go back historically to the time at the end of the war when Oak Ridge began to distribute radioiodine and radiophosphorus, there was a need for exchange of materials between laboratories such as the University of California, MIT, and some of the hospitals that were using the materials for therapy, in order to establish common absolute standards. The various laboratories were found to differ by factors of 2, 3, 4, or 5, and the total range of difference was more than a factor of 10 in the fundamental standards which had always been established by physicists following the rules of calibration. It was not because they were poor physicists. This is a very tricky proposition.

Representative DURHAM. Dr. Neel, why did you select 30 generations? Is there a cause for that, or reason for it?

Dr. NEEL. Yes, sir. If we may oversimplify the problem somewhat and divide mutations into two categories, dominant mutations or recessive mutations, although the dominant mutations will manifest themselves in the first possible bomb generation, it will be a number of generations before the recessive mutations begin to manifest themselves, and they will probably continue to manifest themselves for 20 or 30 generations.

Representative HOLIFIELD. Dr. Bond.

Dr. BOND. With regard to the potential importance of what this number is, may I say the following to see if perhaps Dr. Harris would agree with me. In a hospital, I don't think we would be particularly concerned with an individual that got of the order of 350 or so roentgens. With proper replacement therapy we can save such an individual. Certainly with dogs where we can quantify these things, we can almost double the LD 50 by giving them transfusions, fresh platelets and antibiotics and so forth. We are speaking of a casualty situation here in which medical aid will be very scanty or nonexistent. As a physician I would hate to see people with the order of 350 roentgens or so running around.

Representative HOLIFIELD. Of course, that is exactly what would happen because you would have a depletion of plasma and bone marrow and other things that you would need.

Dr. BOND. Yes. What I am getting at is that I don't care what this LD–50 is, when one has a population exposed to 300 or 350 roentgens without medical care and increased chances of infection, I believe the population is in serious trouble. We cannot take, whatever the number would be, LD–50 as a meaningful parameter.

Representative HOLIFIELD. I think we have discussed that quite a bit. Unless there is something vital to be brought up in that field, we will step to the second question and this is: Would a person who has had an acute dose and survived, and then been subsequently exposed to low dose effects, have an additive or cumulative effect?

Dr. HARRIS. Shall I stick my neck out?

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Representative HOLIFIELD. Let the Chair just state a hypothetical case of a man who has been exposed to 350 roentgens of whole body radiation at some distance from a bomb explosion. Subsequent to that, over a period of the next 6 months, let us assume he accumulates another 150; would that be additive or not?

Dr. HARRIS. My remarks on this come purely from animal experimentation which is at present not even complete. We have exposed animals, mice, in this case—statistical numbers of mice—with doses up to 300 roentgens given at one time. The animals were allowed, then, to remain without exposure for a period of 90 days to allow recovery from the initial exposure to proceed.

At the end of 90 days, the animals were put on a continuous exposure basis at the rate of approximately 2 roentgens per hour which is approximately 50 roentgens per day. To the present time the animals have accumulated during these second exposures something in excess of 5,000 roentgens of gamma rays. Approximately 30 percent to 35 percent of the animals have died after this accumulated dose of 5,000 roentgens. There is at present no statistical difference between the control animals and animals irradiated initially up to 300 roentgens of gamma rays in their time to death or total dose to death.

Representative HOLIFIELD. In other words, the animals who received the 300 roentgens in 1 shot have died in the same percentage as the animals who received an accumulated 5,000 roentgens?

Dr. HARRIS. No, sir.

Representative HOLIFIELD. Will you please correct me?

Dr. HARRIS. Some animals received zero dose initially and others received 300 rad initially. Ninety days later then both of the groups were put into continuous exposure, and both groups have accumulated now something over 5,000 rad. Approximately 30 percent have died after this second accumulated dose. This is 30 percent of all animals whether one looks at the control group which received no exposure initially or the group which received 300 rad initially.

Representative HOSMER. You mean in each group 30 percent has died?

Dr. HARRIS. Yes, sir. There is no statistical difference in the results as yet. The study is not complete. The animals still living are accumulating dose. When the experiment terminates, which we expect may happen after an accumulated dose of 7,000 to 8,000 rad, disregarding the initial exposure, then we will try to see if there is a statistically significant difference in the time to death or total dose to death of the different exposed groups.

Representative HOLIFIELD. This experiment would be in the normal lifetime of the mouse to the point where the natural death would not cover it?

Dr. HARRIS. Yes, sir. In order to take care of this, we also have unexposed groups of the same age that have never undergone any exposure, and this comes into the statistics.

Dr. JONES. Mr. Holifield, I think you were questioning adding up the long-term effects of radiation. The experiment described by Dr. Harris involves acute effects of radiation. The first group exposed was allowed to recover from the acute effects. One can say that the acute effects are a type of illness many, many times more drastic than the accumulated long-term effects from the same exposure. With

both acute and long-term effects present, we would need to have a very large number of animals in order to be able to recognize with confidence the residual effect of 300 roentgens when it is masked by the acute effect of an overwhelming dose of 5,000 roentgens.

I think you would need 10,000 or 20,000 animals before you could expect to see a difference of that sort.

Dr. HARRIS. No. Statistically you don't have to do this with this many animals.

Dr. JONES. You want to detect a very, very small difference in the effects of a very large exposure.

Representative HOLIFIELD. Let me understand this. As I understand it, you took a group of mice with no initial dose and you gave them 50 roentgens a day until they had something like 5,000; is that right?

Dr. HARRIS. Yes, sir. We took the animals that had zero dose; we put them on a daily exposure dose. They are obtaining this dose essentially 24 hours a day except for feeding and watering the animals. They will accumulate and have accumulated now more than 5,000 rad, which is 125 days of continuous exposure. The 5,000-roentgen amount has now killed, in an accumulated dose, 30 to 35 percent of the animals. Sixty-five percent are still living and still accumulating dose.

Representative HOLIFIELD. Did you take another group and expose them to 300 roentgens, give them a period of time to recover, and then put them on the 50 roentgens per day?

Dr. HARRIS. We did.

Representative HOLIFIELD. To where they have accumulated approximately 5,000 roentgens.

Dr. HARRIS. Yes, sir.

Representative HOLIFIELD. And your statistics show the kill is about the same for those?

Dr. HARRIS. Yes, sir; there is no statistically significant difference at the present time.

Representative HOLIFIELD. So the answer to my question, which was "Are the acute and low dose effects additive in any way?"—I meant additive in effect—the answer is "No"; that there is no difference as far as you know at this time.

Dr. HARRIS. This particular experiment indicates that after a recovery—you remember I said recovery, quote, unquote—indicates that the recovery is complete and is not additive to the subsequent exposure.

Representative HOSMER. Let me ask just one more question. Did you have a third group that did not get any?

Dr. HARRIS. Yes, sir.

Representative HOSMER. Thirty percent of them are gone, too?

Dr. HARRIS. No, sir, they are not, because these animals have a lifespan in our laboratory of up to 30 months. We do drop animals off at various times during their lives. The maximum lifespan in our laboratory is about 30 months on animals. The mean lifespan of mice in our laboratory is of the neighborhood of 24 to 25 months. So we are losing a few at 125 days, or approximately 5 months. But the numbers that we have lost so far in these groups do not significantly affect the statistics that I have given, which are not complete. I must emphasize that these studies are not complete.

Representative HOLIFIELD. We understand. Let us go to the next question. Can the panel summarize the various hazards and indicate the conditions under which they should be considered major threats? Is it possible for us now to summarize these different hazards of blast, heat, and radiation and establish any sort of evaluation as to either priority, double or triple kill, or any other factor? Is that question a good question? Do you understand the question? Dr. Tompkins, you held up your hand, and I guess you mean you either did or did not.

Dr. TOMPKINS. Since I posed it to you, I hope I understand it. The point I thought we ought to discuss is that we have considered a variety of types of biological hazards that are created by radiation and fallout. We have taken a look at inhalation, the possibility of ingestion, skin burns, acute gamma exposure from prompt radiation and followed this, then, by considering protracted exposure from fallout fields.

The question really facing us at this point is, can we put these in some kind of perspective that will fit into the picture of nuclear war that the committee is attempting to evaluate? It would appear to me that with the group here and the information at hand, this could to be done rather reasonably.

Representative HOLIFIELD. Dr. Tompkins has taken responsibility for the question. Let us see what some of your colleagues feel about the validity of your question. You are on your own now, gentlemen. Is there any comment on what Dr. Tompkins has said?

Dr. HAM. Mr. Chairman, I would like to amplify again what I tried to give in the testimony yesterday regarding thermal injury from the bomb. I still think, and I want to say again, that I do believe we have the cart before the horse in the sense that we must survive first before we can examine the long-range effects of radiation.

The effects on genetics, the effects of acute versus prolonged dosage, all of these things are very interesting to the radiobiologist or the biophysicist or the doctor, but first I would like to see this panel discuss a little more how we get through the initial phase. By this I mean the first 5 minutes of the catastrophe.

Representative HOLIFIELD. You are not assuming that there will not be survivors in the Nation after this type of attack who will be concerned with factors of radiation, but not necessarily factors of blast and damage, are you?

Dr. HAM. No. I agree, sir, and I am thoroughly in sympathy with the idea of what we can do with the survivors after we have had our initial mortality whatever that would be. I do think we also have to consider what the condition of these survivors will be. My point is that I am afraid that many of them would be injured before many of these later effects came upon them. I am thoroughly in sympathy with anything we can do to vitiate these delayed effects that are going to come later. I do think that the immediate effects come primarily in the discussion.

Dr. DUNNING. Let me start with one with which we may all be in agreement, and that is inhalation. This would not be of the same degree of problem as the other factors. In this regard, Dr. Herbert Decker at Fort Dietrick, Md., did a small experiment for us. In regard to the question asked by Mr. Holifield, he took a handkerchief

eight folds thick and a turkish towel two folds thick and held it over his nose to see what filtration would be accomplished. Obviously this depends on how well it is held. If it is leakage, you have lost your effect. With a tight fit, he found it filtered out 85 to 90 percent of these 1-micron spores. This would be helpful and if you had the material available you would use it. I don't think you would spend valuable time thinking about it and doing things about it when there are other more protective measures that are compelling.

Representative HOLIFIELD. If you are badly burned you would not be worried about what you are breathing.

Dr. DUNNING. That is right. Nor would you be running around in a high-radiation field looking for a handkerchief or turkish towel.

Representative HOLIFIELD. I appreciate your point. In the last part of the hearings we will get to survival techniques. I think the thing we want to consider now, if there is a possibility of comparing what is the greatest damage to the greatest number of people—blast, fire, or radiation outside of the area of those killed by blast and fire. Maybe these are so overlapping that you cannot separate them.

Dr. TOMPKINS. This is the point, Mr. Holifield, I think perhaps we can consider it most clearly by considering two separate cases. The first case, the region around any detonation which is within the range of what are called the prompt effects—this is blast, the thermal effect which Dr. Ham has mentioned, any prompt nuclear radiation which Dr. Harris discussed, and also any large doses of ionizing radiation coming from the fallout deposits, but still within the physical region which is reached by these prompt effects. The reason for suggesting doing it this way is that the effect depends on where ground zero was and what happened to be around it. If effects are circular, they happen instantaneously. I think this is the region where the most severe consequences occur. I think I would like to propose to my colleagues on the panel that within this region in the interior, one is subjected to multiple threats; blast, thermal, prompt ionizing radiation, and even perhaps protracted ionizing radiation. Consequently one does not have to distinguish too sharply how important they are relative to each other. Everything is very bad within this region, which is normally called the region of total destruction. There is a region beyond that where the blast and thermal and perhaps prompt ionizing radiation overlap. Do you want to put any limits on this? I would say in the second region one could get all three. You could have thermal burns. You could have some of the type of displacements or direct blast injury that Dr. White talked about, or one can also be exposed if not to prompt radiation, at least in some segments of it, to high intensity from the local fallout.

Representative HOLIFIELD. Which would be partially lethal in effect and would injure people partially.

Dr. TOMPKINS. This is true, but the significant thing I want to point out is that so far we have talked about virtually immediate lethality—killing by blast, killing by thermal, and by highly intense ionizing radiation. We have yet to mention inhalation, ingestion, skin burns or many of the other hazards. So this is the group that is tremendously dangerous from the standpoint of immediate lethality. It does include the blast problem, the thermal problem, and the ionizing radiation external gamma. I would limit it to those.

In this region of severe trauma when we talk about radiation doses, we are talking about large ones. I would propose that this is a description of relative effects at least in this region.

Representative HOLIFIELD. Dr. Ham, would you accept that general description as being a valid appraisal?

Dr. HAM. Yes, I certainly would. If I remember correctly in the Monday testimony, to try to get some figures here, I believe that Mr. Quindlen said that 68 million people would be involved in this problem within what I believe he defined as the target complex. I am not quite sure of these figures, and perhaps some other member of the panel can correct me.

Representative HOLIFIELD. There have been no figures given, Dr. Ham, on the casualty figures. The figures of people killed and people injured will be given in the morning.

Dr. HAM. No, sir, I did not mean that. It was not my intention to calculate casualties. I just wanted to call attention to the fact that of the total population of the United States—is it correct that approximately 68 million would be involved within what we would define as the target complex?

Representative HOLIFIELD. I don't have that figure. That figure will be given in the morning. I think the whole Nation would be involved. As to how many people would be killed, injured or made sick, I think it is another problem.

Dr. TOMPKINS. I think that is entirely correct. I believe from the standpoint of this panel we would be better off to talk about relative vulnerability because the actual number of casualties depends entirely on who happens to be at these particular localities. However, the relative vulnerability depends on the magnitude of the threat on the one hand, and the sensitivity of the person or his situation on the other. These things, I think, can be met in a way, and I have attempted to do so.

Representative HOLIFIELD. I think unless there are further comments on the relativity of the damage and the priorities of the damage, we will now ask whether any member of the panel wishes to bring up a point pertinent to the injuiry, either in the form of a question of testimony or to bring in a factor which might have been overlooked in the area of inquiry. Dr. Newell has his hand up.

Dr. NEWELL. The total number of casualties obviously will depend upon the efficiency and the goodness of centering. If the goodness of centering is great, then the primary destruction will take in the metropolitan areas and the total number will be very large. If we guess that 40 percent of the population are killed more or less outright, by the blast and fire damage, that is. However, whatever the number is, whatever the proportion is, and whatever the LD 50 for man is, we can be sure that there will be insufficient medical attention to take care of the borderline ones, and this makes it a matter of chance how many recover. But the thing that we should look at, I believe, is what happens to the people who do recover. In other words, we should be paying attention to the remaining population that is not killed. We have not said anything about the effect of remedial or preventive measures on this. The matter of shelters is not able to stop the primary destruction, but fireproofing and shelters against gamma radiation and fallout irradiation are able to have a very large

influence upon the numbers that do survive. In other words, whatever the ratio between the primary destruction and the rest of the population is, there is a large fringe area in which even very modest attempts at prevention and shelter will yield a very large reward. I think this is what we ought to keep our eyes on.

Representative HOLIFIELD. Dr. Newell, we have a place for that on the agenda. If you will consult the agenda you will find that on page 12 and on page 13 we do take up the survival measures, and we will have a panel at the proper time to talk on those things. We are now only concerned with the damage which has occurred. I want to correct my statement to you, or clarify it, Dr. Ham. The number you referred to was given in testimony by Mr. Quindlen and it refers to a little bit different situation than I thought you meant. He said the next chart shows the distribution by target. One hundred and eleven of the targets were Air Force installations, total weight 645 megatons, the size of weapons used on Air Force installations. Seventy-one of the targets were critical target areas. By this, we mean concentrations of population and industry. They contain about 68 million of the country's population and 110 weapons were used against these areas for a total weight of 567 megatons.

I call to your attention that they were all Air Force and military installations and AEC installations, many of which were outside of the 71 critical targets. So there were a great many more people involved than that figure you used.

Dr. TOMPKINS. Dr. Harris indicated he had a couple of comments he would like to make.

Representative HOLIFIELD. Dr. Harris.

Dr. HARRIS. In regard to Dr. Tompkins' specific question, I would like to lay this proposal before the panel. Talking about primary events now, that one consider blast, thermal and initial nuclear radiation, whether it be from the initial radiation or from close-in fallout, primarily. The subjects of ingestion, inhalation and beta ray burns should be a secondary consideration to the whole problem, with the reservation that lay personnel have been told what to expect and what to do in case of these latter three items.

I would just like to lay this before the panel.

Dr. TOMPKINS. I would have to agree. The line of demarcation we can profitably discuss is the immediate effects. If we can agree on the hazards that are the greatest, in those areas, then we can talk about the outlying areas where Dr. Newell says the potential survivors actually are, and then what can one expect in these places. Outside of the immediate area, the immediate threat is fallout. The local fallout, I think, still presents as its major threat the external rays coming from the gamma ray emitter. Therefore, the first problem of survival under these conditions is to find a means of protection against this threat which at this time is still the overwhelming threat. This is my feeling. If one can defeat it to a reasonable degree, or if one is fortunate enough to be in a region where the gamma threat is not large enough to be disastrous, then one should still be aware of and take precautions against, where necessary, the secondary effects, such as the skin burns which Dr. Bond mentioned, the problems of ingesting radioactive material which Dr. Dunning has talked about, and the problem of inhalation which Dr. Cohn has talked

about. It is fortunate that effective protection against each of these is readily available, and if understood could remove many situations which in the absence of information would lead to hazards. That is just about the line of demarcation that fits this kind of picture, I think.

Representative HOLIFIELD. I agree with Dr. Tompkins. We cannot carry this out. This is a study that needs to be made. As you know we have excluded certain areas from the study at this time. Of course, all of the problems of the population that survives without adequate transportation, with contaminated food supplies, disrupted water supplies and other utilities, all of those problems are a tremendous field in themselves. Time will not permit us to go into it, nor the jurisdiction of this particular subcommittee.

Gentlemen, if there is nothing else to be brought up before the panel, I want to thank each and every one of you for participating personally in the testimony and also in the panel discussion and excuse you at this time.

The committee will resume tomorrow in this room at 10 a.m.

Casualty estimates will be presented in the morning by Mr. Quindlen of the OCDM on blast, fire, and immediate radiation. There will be a discussion of long-term casualties by Dr. Dunning of the Atomic Energy Commission. This discussion will be followed by a presentation on survival measures. We have brought over, because we were behind time, to follow in the afternoon, the environmental contamination which should have preceded this. Dr. Bernard F. Trum of Harvard University Medical School will testify on the effects on animals, Dr. Reitemeier on the effects on soils and crops, Dr. Laugh from the Food and Drug Administration on the contamination of processed food. Dr. Kermit Larsen on long-term effects, and Dr. John Wolfe, Division of Biology and Medicine of AEC, on the long-range implications.

Thank you, gentlemen.

(Thereupon at 5:45 p.m., Wednesday, June 34, 1959, a recess was taken until Thursday, June 35, 1959, at 10 a.m.)

BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

THURSDAY, JUNE 25, 1959

CONGRESS OF THE UNITED STATES,
SPECIAL SUBCOMMITTEE ON RADIATION,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D.C.

The subcommittee met at 10 a.m., pursuant to recess, in room P-63, the Capitol, Hon. Chet Holifield presiding.

Present: Senators Anderson (chairman of the full committee), and Hickenlooper; Representatives Durham (vice chairman of the full committee), Holifield (chairman of the subcommittee), Price, Van Zandt, Hosmer, and Bates.

Also present: John T. Conway, assistant director, Richard T. Lunger, staff consultant, and Carey Brewer, special consultant, Joint Committee on Atomic Energy.

Representative HOLIFIELD. The committee will be in order.

Yesterday afternoon a panel of experts summarized and discussed the highlights and implications of testimony received on the biological effects of a hypothetical nuclear war.

This morning we will receive from Mr. Eugene Quindlen of the Office of Civil and Defense Mobilization, a summary of the casualty estimates from blast, fire, and thermal effects from the hypothetical attack set forth by this committee.

The Chair has requested the Office of Civil and Defense Mobilization to rerun their computations of casualties on the basis of a new formula which has been introduced during these hearings.

He has also asked them to make a breakdown of the cities of the Nation on both the old and new formula. The breakdown will be ready for distribution at 10 o'clock tomorrow morning.

Later this morning Dr. Gordon Dunning of the Division of Biology and Medicine of the Atomic Energy Commission, will discuss the late casualties resulting from radiation.

Testimony will then be on technical considerations of survival methods.

Our witness for this topic will be Mr. W. E. Strope, of the Radiological Defense Laboratory, on survival measures.

Mr. Quindlen, will you please come to the witness stand, sir?

STATEMENT OF EUGENE QUINDLEN,[1] OFFICE OF CIVIL AND DEFENSE MOBILIZATION

Mr. QUINDLEN. Mr. Chairman, members of the committee, this presentation is an analysis of the effects of the attack specified by the committee on the people of the United States.

As you recall, from our discussion of the other day, this is an attack of 263 weapons ranging from 1 to 10 megatons upon this country for a total megaton average of 1,446.

The figures which I will present today are national figures only (p. 650).

As you requested, we are preparing a State and metropolitan area breakdown of these figures and will present them to the committee as requested, tomorrow morning.

There are many variables in placing an attack of this type and these variables can affect the final nature and place of an attack and can affect the number of casualties produced by an attack.

The specific attack described by the committee on these targets and under these circumstances, could have killed about 19.7 million persons the first 24 hours. An additional 22.2 million persons would have been so badly injured that they would subsequently die of the injuries, and there would have been about 17.2 million additional persons injured who could be expected to recover from the injuries received.

The chart which we have there summarizes these figures. Of those killed, about 25 percent would have died as a result of radiation alone, and about 75 percent as a result of blast and thermal injuries, combined to a great extent with radiation injuries.

Many of those people close in to a weapon who would die of blast and thermal injuries would also have received sufficient radiation to kill them. We have listed these, however, as blast and thermal injuries.

Of the surviving injured of 17.2 million, about 6.3 million would have had blast and thermal injuries and about 10.9 million would have had fallout injuries alone. This would be a serious blow, but even with this weight of attack we should look to the question of what is left, what does the country look like at this point.

First of all, about three out of every four persons in the United States would survive this particular attack. On the other hand, one out of four would not survive. These are the facts of life if a nuclear war should ever come to our borders.

This is the picture which OCDM has been portraying for the American people over and over again in speeches, in pamphlets, on the radio, on television, and in the newspapers.

This threat and means to meet it were highlighted in the pamphlet "Facts About Fallout," of which 8 million copies have been distributed since its initial publication in 1958, and in "Handbook for Emergencies," distributed in 42 million copies.

It is reiterated in the new OCDM pamphlet, "The Family Fallout Shelter," which is now being distributed in total number of 50 million copies.

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[1] See biography, p. 712.

In the introduction to that pamphlet Governor Hoegh makes this statement:

> In an atomic war, blast, heat, and initial radiation could kill millions close to ground zero of nuclear bursts. Many more millions, everybody else, could be threatened by radioactive fallout, but most of these could be saved.

I wish to point out to the committee that the population figures which we use for damage assessment purposes are those from the 1950 census. There have been methods of updating these population figures developed for application to individual cities based on the actual growth of these cities in the last 9 years.

The development of a machine program to reflect specific increases in population for every one of our 24,000 population points, is an expensive process for which we have not expended the funds.

Population has increased about one-sixth from 1950 to 1959. The growth in individual areas has been much greater or, in some few cases, much less, than this.

It is possible that the national figure as shown on our chart would be about one-sixth higher if we had available in our machine system present population figures which just last week reached 177 million.

This compares with 151 million on the 1950 population basis.

The only method of getting up to date figures for each of those 24,000 points would be an actual count, a census, which is an expensive job. It is so expensive that it is done only every 10 years on a national basis.

Now, we do not feel this rule of thumb can be applied to individual areas in the United States and we will not do this in the materials which we present tomorrow in the individual target areas. This is a national summary of the results of this attack on the people of the United States.

We will be happy to supply for the record for tomorrow morning any additional material regarding this assessment which the committee might desire.

Representative HOLIFIELD. Thank you, Mr. Quindlen.

The Chair wishes at this time to thank the members of the OCDM for their cooperation in working out these figures and taking this additional task for tomorrow morning.

Governor Hoegh has been very cooperative as usual in response to the committee.

The Chair would like to make a short statement.

I am hopeful that the figures and facts resulting from this hearing will not fade into forgetfulness. They have not been given for the purpose of temporary publicity. These facts can be used to inform all of our citizens on the nature and hazards of nuclear war.

They can also be used in evaluating our military and foreign policy because it is built around the central factor of weapons offense and defense.

We have not faced up to the problem of survival of our civilian population in the event of nuclear attack. Admittedly, the problem is difficult and expensive, but it is not as difficult as many of the technological problems we have solved, nor would it be as expensive.

It is impossible to calculate the value of a single human life. How can we set a value in dollars on 42 million or 51 million lives in the United States?

We have been given facts regarding shielding against blast, fire, and radiation, and will be given more before the day is over.

There is no doubt that preventive measures can be taken which could save tens of millions of human lives in the event of a nuclear war. These measures are within our technological and economical ability.

The question, in my opinion, is not can we afford to do it; it is can we afford not to do it.

We, as a Nation, wish to survive and perpetuate our free way of life.

Representative HOSMER. Mr. Chairman.

Representative HOLIFIELD. Mr. Hosmer.

Representative HOSMER. I think in viewing these figures there are very grave perspectives from which to view them.

We should first emphasize it is based on a hypothetical situation.

Second, that the figures are for an attack if it should occur, and the "if" is a very large one.

Third, that should the "if" materialize, it is highly unlikely that it would materialize in any way, shape, or form, of the hypothetical situation.

If there is one thing certain about the future it is that we cannot predict it with any degree of accuracy.

There is also the correlative that you have so well pointed out, that we look not only at the casualty figures, but at the survival figures.

There is a substantial difference between individual survival and national survival in the event of a catastrophe of this nature.

Frankly, from the studies that I have read of this situation, yours and others, these figures are actually less than I had anticipated they would be from the previous estimates that had been made.

Mr. QUINDLEN. There is another point, if I may, Mr. Chairman, that we should emphasize as we did when the hearings opened, that this is a net attack. This is the net figure resulting upon the United States as supplied to us by the committee without respect to the size of the force which the enemy might have had to have to achieve this result.

He would have had to start, of course, with substantially larger force and substantially more weapons to wreak this havoc on the United States.

Representative VAN ZANDT. Mr. Chairman.

Representative HOLIFIELD. Congressman Van Zandt.

Representative VAN ZANDT. Mr. Quindlen, is it not true that in setting up the hypothetical situation the ability of our own defenses was not taken into consideration; that is our ability to intercept and to destroy oncoming missiles?

In a few words, you gave the enemy the full value after getting over targets in the United States, some 260 weapons of various sizes.

Mr. QUINDLEN. Yes, sir; we did not do this. The committee did this.

Representative VAN ZANDT. Yes, a hypothetical situation.

Mr. QUINDLEN. Yes.

Representative HOLIFIELD. I will have to state that all these matters were taken into consideration in setting up the assumptions. It would be ridiculous to suppose that only 260 weapons would be used

in an attack upon any major nation when many thousands of weapons exist and thousands of bombers are available and 400 to 500 submarines as one nation has, and many other factors.

So after very carefully going over these we established a hypothetical net delivery. We did take into consideration the capacity to defend. After we got through with our assumptions, we submitted the whole pattern to a man, I believe, who is recognized as one of the great military experts. Lt. Gen. James M. Gavin, and he wrote me the following letter under date of June 20:

> I have examined the theoretical nuclear attack pattern as presented by your committee in the hearings beginning June 22, 1959. I consider your assumptions to be entirely realistic and well within the capabilities of a potential aggressor.

So this is not a figment of the imagination. This could happen here and it could happen in much worse form than we have here.

It could also be less than that. We must be fair on that.

Representative VAN ZANDT. Mr. Chairman, of course, I agree with you that we set up this hypothetical situation based on the fact 260 weapons got over the targets of the United States, but I think the American people are entitled to know the weapons guidance systems have not yet been perfected to the point where they can guarantee accuracy.

It is a known fact we give the enemy capabilities of having 100 missiles with nuclear warheads. Based on the present estimates only 50 percent of those will get in the area of targets and less than 25 percent will actually get over point zero of the targets.

So if you fire 100 weapons you are only getting 25 of them over point zero of the target.

I think that should be taken into consideration.

Again I go back to the fact that this is a hypothetical situation. I commend Chairman Holifield for these hearings because I think they are highly informative and the American people are entitled to the information that they are receiving.

Representative HOLIFIELD. Would you care to describe any detail as to how this was worked out, Mr. Quindlen?

Mr. QUINDLEN. In what way, Mr. Chairman?

Representative HOLIFIELD. Would you describe the process? · You took the different areas and their population and you actually applied known effects of nuclear weapons to the pattern?

Mr. QUINDLEN. Yes, sir. We have a machine system which we use which locates the resources of the United States at 24,000 points. It is impossible for efficient machine methods to locate people exactly as they are with individuals.

So you group the resources, people, and dwellings, record them against 24,000 points to which you apply a Utm coordinate. Then you measure the effect of each of your weapons by machine against each of those points to calculate the casualties.

Representative HOLIFIELD. You have confidence that this is the best known system of computation?

Mr. QUINDLEN. Yes, sir.

This is an excellent national system. When you apply this to an individual area, because of the fact that we are dealing with 24,000 points and not a million points, you get some slight inaccuracies in individual areas.

As a national assessment system we think it is an excellent tool.

Representative HOLIFIELD. For the record, may I ask you this question——

Mr. QUINDLEN. Yes, sir.

Representative HOLIFIELD. Were the effects computed from the current handbook "Nuclear Weapons Effects," which was published in June 1957?

Mr. QUINDLEN. Yes, sir.

Representative HOLIFIELD. And the new effects will be given to us in the morning?

Mr. QUINDLEN. Yes, sir.

Although we do not feel that we have the final figures, we don't feel there will be an appreciable difference. We feel that some of the people who would be killed by blast and thermal under the formula which we are now applying at the request of the committee, would have had a higher dose of radiation, but the original dose calculated under our system would still have been enough to kill them.

We think the differences will be theoretical. Of course, these are both theoretical formulas. Also, the formula which we have been using, t to the minus 1.2, shows subsequently a higher rate of radiation than the formula which the committee has asked us to use.

Representative HOLIFIELD. If the new formula were used it would have a very important effect upon the length of time of intensive radiation. It would, in effect, be advantageous from the standpoint of shelter, of the time required to remain in the shelter?

Mr. QUINDLEN. Yes, sir.

We think it will have this effect, and we are looking at it from this viewpoint.

Representative HOLIFIELD. Are there any further questions?

Representative VAN ZANDT. Mr. Quindlen, on your estimate that 17.2 million additional persons could be expected to recover from injuries received. Some of these injuries, of course, would come from the dose of radiation received; is that right?

Mr. QUINDLEN. Yes, sir.

Actually, almost two-thirds of them would have had radiation injuries. It is these injuries we are referring to there.

Representative VAN ZANDT. I imagine you took into consideration the debris that would be placed in the atmosphere and also the downwind movement of a cloud and the distribution of that radioactive debris over the populated areas?

Mr. QUINDLEN. Yes, sir.

Representative HOLIFIELD. Mr. Quindlen, have you any figures to give us on the increase in global fallout which would result from this type of attack?

Not only am I asking you the question on the basis of the 1,500 megatons approximately delivered on the United States, but 2,500 megatons delivered on an enemy country from our oversea bases.

Mr. QUINDLEN. Sir, I am not prepared to answer that question. We can get the answer for you.

Representative HOLIFIELD. Will you, please, try to get that answer tomorrow morning, too?

Mr. QUINDLEN. Yes, sir.

Representative HOLIFIELD. I believe I asked for that answer before because the whole reason for putting in additional——

Mr. QUINDLEN. No, sir; this request was not made of us. I think there is another witness to present that.

Representative HOLIFIELD. Dr. Machta?

Mr. QUINDLEN. Yes, sir; of the Weather Bureau, not OCDM.

Representative HOLIFIELD. It is not the committee's purpose to go into the many problems in the postattack phase with which the population would be faced. If these tonnages were dropped on the 71 populated centers it would pretty well destroy all water, gas, and electrical facilities, would it not?

Mr. QUINDLEN. Yes, sir. We did not run an assessment of these facilities in this attack.

Representative HOLIFIELD. No, but the size of the weapon and its known effects would cause that destruction, would it not?

Mr. QUINDLEN. Yes.

Without having done an assessment of this particular point, the facilities would probably have been destroyed almost in direct proportion to the population.

Representative HOLIFIELD. In view of the fact that these are all ground bursts?

Mr. QUINDLEN. Yes, sir.

Representative HOLIFIELD. This would also wipe out the railroad transportation yards in the cities affected, would it not?

Mr. QUINDLEN. Mr. Chairman, each of these attacks, with the placement of the weapons has a specific effect, each one a little different from the other. Certainly many transportation facilities would be destroyed.

I could not say without running an assessment on transportation specifically the direct effect this attack would have on transportation. Our assessment here was directed as requested to dwellings and population.

Representative VAN ZANDT. Mr. Chairman, may I ask a question?

Representative HOLIFIELD. Mr. Van Zandt.

Representative VAN ZANDT. Mr. Quindlen, in developing the estimates which you have presented to the committee, did you take time to go back and compare them with the estimates given this committee in 1957?

Mr. QUINDLEN. Yes, sir; I am familiar with the estimates there. That attack was an attack which we prepared at our headquarters to test certain internal policy matters. It was overdesigned in the sense that the weapon composition was not in our opinion at this time a realistic one.

It was far different from the assumptions of this attack and it produced more casualties than this attack.

Representative HOLIFIELD. It was a great many more megatons?

Mr. QUINDLEN. Yes, sir; it was. Approximately 2,500 as I recall it.

Representative VAN ZANDT. 250 weapons, about 2,500 megatons?

Mr. QUINDLEN. Yes, sir.

Representative VAN ZANDT. In other words, the additional information when placed at your disposal since 1957 has made it possible for you to give us a better estimate of what would happen under these conditions?

Mr. QUINDLEN. I would not put it exactly that way, Mr. Van Zandt. I think that the assumptions underlying the assessments here are more realistic than those in the 1957 attack.

This was not too important at the time we made the 1957 attack because this was not intended for public use and it did not affect in our opinion the answers which we were trying to get on certain broad policy matters.

It was intended as an internal staff exercise of our own.

Yes; I think the assumptions underlying this assessment are more realistic.

Representative HOSMER. Mr. Chairman.

Representative HOLIFIELD. Mr. Hosmer.

Representative HOSMER. As to electrical facilities and so forth, another study I have seen based on an attack, a hypothetical attack of this nature, the conclusion was that over half of the electrical generating facilities would survive. Does that correspond roughly with your views, Mr. Quindlen?

Mr. QUINDLEN. I have seen assessments running from a half to a quarter destroyed, but I have also been quite impressed in any examples that we have used, for example, in an Operation Alert where we have had outstanding members of various public utilities working with us, at the speed, relative speed, with which they feel many of the electrical facilities could be restored, primarily because of their plans for interlocking various systems throughout the United States.

Representative HOSMER. The same is true roughly in connection with our rail and highway systems bypass capacities for facilities destroyed in the metropolitan area——

Mr. QUINDLEN. Yes, sir; I think the situation is improving.

Representative HOSMER. I have a figure in mind regarding the agriculture industry of over 90 percent nondamage. Does that sound reasonable?

Mr. QUINDLEN. Yes; if we are speaking of blast and thermal this might be reasonable.

However, there would be fallout under this attack pattern on a substantial portion of the agricultural land, of possibly 40 percent.

Representative HOSMER. I suppose the industrial casualty of the Nation would be roughly in relation to the casualties?

Mr. QUINDLEN. Yes, sir; but for individual parts of the industrial capacity this might be greater or less, depending on the particular attack, and the concentration or dispersion of particular industries.

Representative HOSMER. Thank you.

Representative HOLIFIELD. Thank you very much, Mr. Quindlen.

Mr. QUINDLEN. Thank you, Mr. Chairman.

(The full statement of Eugene J. Quindlen follows:)

NATIONAL CASUALTY ESTIMATES

Mr. CHAIRMAN: This presentation is an analysis of the effects of the attack specified by the committee upon the people of the United tSates. The figures which I will present today are national figures only. We are preparing a State and metropolitan area breakdown of these figures and will present them to the committee as requested on Friday.

Many variables can affect the final nature and place of an attack, and many variables can affect the number of casualties produced by an attack, but an attack of this type specified by the committee on these targets and under these circumstances could have killed about 19.7 million persons the first day; 22.2

million additional persons would have been so badly injured that they would subsequently die of the injuries, and there would have been about 17.2 million additional persons injured who could be expected to recover from injuries received. This chart summarizes these figures.

Of those killed, about 25 percent would have died as the result of radiation alone and about 75 percent as the result of blast and thermal injuries, combined to a great extent with radiation injuries. Of the surviving injured, of 17.2 million, about 6.3 million would have had blast and thermal injuries and about 10.9 million would have had fallout injuries alone.

This would be a severe blow but even with this weight of attack, about three out of every four people in the United States would survive. These are the facts of life if a nuclear war should ever come to our borders. This is the picture which OCDM has been portraying for the American people over and over again in speeches, in pamphlets, on radio, on television, and in the newspapers. This threat and means to meet it were highlighted in the pamphlet, "Facts About Fallout" of which 8 million copies have been distributed since its initial publication in 1958, and in "Handbook for Emergencies" distributed in 42 million copies. It is reiterated in the new OCDM pamphlet, "The Family Fallout Shelter," which is being distributed in 50 million copies. In the introduction to that pamphlet, Governor Hoegh makes this statement: "In an atomic war, blast, heat and initial radiation could kill millions close to ground zero of nuclear bursts. Many more millions—everybody else—could be threatened by radioactive fallout but most of these could be saved."

I wish to point out to the committee that the population figures which we use for damage assessment purposes are those from the 1950 census. Methods of updating this population have been developed which can be applied to individual cities based on the actual growth of these cities in the last 9 years. The development of a machine program to reflect specific increases in population for every one of our 24,000 population points is an expensive process for which we have not expended the funds. Population has increased about one-sixth from 1950 to 1959. The growth in individual areas has been much greater or, in some cases, much less than this . It is possible that the national figure as shown on our chart would be about one-sixth higher if we had available in our machine system present population figures which just last week reached 177 million. We do not feel, however, that this rough rule of thumb can be applied to individual areas.

This is a summary of the results of this attack on the people of the United States. We will be happy to supply, for the record, any additional material regarding this assessment which the committee might desire.

Casualties (in millions)

Type of attack effects	Killed 1st day	Fatally injured	Surviving injured
Blast and thermal	19.7	11.5	6.3
Fallout		10.7	10.9
Total	19.7	22.2	17.2

Representative Holifield. Our next witness will be Dr. Gordon Dunning, Division of Biology and Medicine, Atomic Energy Commission.

He will speak to us on the delayed casualties from radiation.

STATEMENT OF DR. GORDON DUNNING,[1] DIVISION OF BIOLOGY AND MEDICINE, ATOMIC ENERGY COMMISSION

Dr. Dunning. Mr. Chairman, in the interest of time, I will summarize my remarks.

[1] See biography, p. 432.

Representative HOLIFIELD. Well, we cut you short yesterday, Doctor. I have not seen your statement yet, I have not had time to look at it, but we want to give you the time that you need to do it properly. (Dr. Dunning's formal statement appears on p. 436.)

Dr. DUNNING. I think we can do it in a summary statement.

If the committee will be kind enough to just thumb through the pages I will summarize as we go along. If you will be kind enough to turn over four pages, which starts the text of the paper, at the outset I would like to make it clear that I am sure full consideration has not been given to all the factors involved here.

I am sure there are some factors that have perhaps been overlooked, no major factors, I hope.

I do think, however, we can give some perspective to the relative potential effects. For purposes of calculation rather precise values and methods have been used in estimating these biological effects. This might imply a degree of knowledge and understanding that does not in fact exist.

With those qualifications, again I think we should make clear that the dominant hazard is the immediate blast, thermal and radiation, and the early deaths from heavy fallout.

Having said this, the other problems that remain of principal interest are the internal radiation of the thyroid and gastrointestinal tract by ingestion of contaminated foods and water, the production of leukemia and bone tumor by external radiation and internal emitters, strontium 90, and so forth, life shortening, and genetic effects.

Again I would like to emphasize in many of these cases I am acting as a reporter. This is the work done by many scientists over many periods of years.

I have attempted to make an evaluation of their work.

Turning over to page 4 of the main text, unfortunately we strike a knotty problem immediately. If I may, I would like to try to clarify this problem of decay rate.

I hope I do not make it less clear.

Originally, back in the early forties, Drs. Way and Wigner took the fission product decay and tried to estimate how fast this activity decreased with time.

They were discussing the actual disintegration of the atoms. They were not discussing dose rates. From their data others have tried to extrapolate and say so many gamma protons come off per disintegration and each of these protons has so much energy and if you spread this material on an infinitely flat plane, you might get a radiation flux of so much, say, 3 feet above the plane and this might give you a certain dose.

Now, this is a long cry from the original intent of the data. In fact, the surprising thing is how closely it approximates the facts of life, not how far they differ.

As to the actual decay, if we had fallout in Washington and we went outside with a meter and we took a dose rate reading and then we asked the question what would be the reading this afternoon or tomorrow and we want an answer quickly, we would still use t to 1.2.

I would, and I think most of the other people would. It is an approximation; but it is a very convenient number.

As you go out in time, then it is true that the decay will vary from this t to the 1.2. In fact, it never does go precisely this way.

It decays less rapidly at some times and other times more rapidly.

As you go out a matter of a few months, then the decay dose drops off more rapidly than would be expected by this theoretical analysis. This is not new information. This has been calculated by the British several years ago, and a document that we have on the fallout in the Pacific of 2 years ago indicates the dropoff curve from that expected.

It is still a good number out to a period of a few months.

It is also a good number, if you are trying to add up all these dose rates in time and ask what is the integrated dose.

If you have early fallout, say, 1 or 2 hours after the detonation and ask what will be the total out of door dose from now until a period of a few months from now, t to the 1.2 is still a fairly good approximation.

If, on the other hand, you evacuate, or do not move into an area until several months later, then the dose rates might well be less than calculated by the old formula.

As to the fallout pattern, Mr. Holifield, these are based on the effects of nuclear weapons as you know. Those patterns as described in that book were not calculated by putting one Kt of fission products per square mile and then trying to estimate what would be the gamma radiation level, but, rather, going over the mass of past data and saying "Here, we know we have a detonation of such-and-such a size. We have actually gone out and measured dose rate readings, so those contours you see in this book are the best, I am sure they are not perfect, but they are the best contours of dose rates one can draw in relation to a given size bomb."

That means, then, that when we use these as models and draw the patterns they are fairly good approximations of the fallout.

I am sure that as we learn more and discuss this more among ourselves that we are going to refine and improve, but personally I question the need or the desirability of going back and recalculating all these patterns.

Representative HOLIFIELD. But your own nuclear handbook states that they are idealized patterns. It does not claim that they are accurate in shape. They are idealized from the standpoint of convenience.

It is obvious that each pattern would be different, probably, from another pattern because of the vagaries of wind and terrain which would obtain in the case of each explosion.

So as long as the general reading at a distance is concerned, the only factor I might see that would be important would be the overlapping. In other words, if the pattern were irregular and wide as Dr. Machta showed in his chart, and he assured us that those patterns were taken from actual readings of blasts, then it seems to me you would have probably more overlapping than you would in the idealized patterns that we use here.

This might raise the intensity in the area of overlap but it also might shorten the distance of the drift.

Dr. DUNNING. That is right, sir. I would certainly agree that one of our greatest efforts should go into improving the model of the idealized pattern.

Obviously it will be a rare occasion when we get wind precisely of this idealized pattern.

Representative HOSMER. In relation to the total aggregate, your point is the futility of attempting to predict the unpredictable?

Dr. DUNNING. I think that is it. It is not completely unpredictable. I am saying in this kind of business if you can predict within a factor of two, you are pretty well off.

I think we are fooling ourselves if we think we can do better at this stage. We will learn more as we go along.

Representative HOLIFIELD. I do not think you mean that, do you, Doctor? When we have had these actual patterns showing that they are different than this you would not contest Dr. Machta's testimony as to the actual readings on the patterns which he showed us from his chart, would you, sir?

Dr. DUNNING. No, sir; the point of uncertainty lies in not being able to know precisely what will the wind pattern be like.

Representative HOLIFIELD. Oh, as to the future. But if you did have records of known wind patterns and size of bombs and location of drop and so forth, the pattern would be quite different from theses idealized patterns?

Dr. DUNNING. I suspect they would.

Representative HOLIFIELD. Whether the overall result would be different, I am not able to say. The end result of casualties might be fairly close.

As I understand Mr. Quindlen, he said this morning he thought the new formula for computation might bring out about the same number of casualties.

Dr. DUNNING. Well, actually, when you get into biological effect of this nature we are happy if we can estimate within a factor of two.

Representative HOLIFIELD. Yes.

Dr. DUNNING. Turning, then, to page 5 of the main text, we took a relatively heavy fallout area and asked the question, What might be the result there?

The reason for doing that was to take all of the areas of the country with all of the varying degrees of fallout would be a tremendous task which certainly could be done eventually, but in preparation for these hearings we simply said, let us look at the worst and from this, one can extrapolate downward.

In other words, there are some areas where there is essentially no fallout so the results are essentially zero.

But taking the worst we will look at the heavily contaminated area which we will define as something in the order of 3,000 or 4,000 r. per hour at H plus 1.

Looking first, then, at the problem of the food supply, the radiation of the thyroid and gastrointestinal tract—the problem here is the gross contamination of the foodstuffs from the fission products generally and from the iodine specifically.

Now, both of these sets of isotopes, the gross fission product and iodine isotope decay rapidly. So we are talking about a real problem as we will see in a moment, but a problem which will persist several weeks or a few months, not years.

Referring to my statement (p. 436), there are the calculations so that one in this kind of business can go over them and agree or disagree.

The assumptions are there, and the calculations are there and certainly I am one of the first to say that there are large uncertainty factors.

But taking the numbers as they are developed one sees that in this heavily contaminated area the degree of iodine is very large. The intake of iodine for infants and young children would be principally from milk.

But this is such a heavily contaminated area it is doubtful if the cows could live. If they did live, and did give milk, then it is possible that a single pint of milk, during the first week of fallout, could contain enough iodine to completely destroy the thyroid of the child and thus the child.

It is a real problem of which there is no complete solution at the moment. We are progressing with studies at the University of Tennessee farm at Oak Ridge to see if it is possible to remove iodine from milk.

Right now we are just in the pilot stage of those studies.

Representative HOLIFIELD. This windscale incident in England must have given you a great deal of data on this point?

Dr. DUNNING. Yes, sir; it did. In fact, it gave us about the only direct data we have. The rest are theoretical calculations.

Representative HOLIFIELD. How long was that area quarantined as far as using the milk is concerned?

Dr. DUNNING. I do not recall specifically. I do know they dumped the milk for a period of several days at least in some of the areas. This, of course, was on the basis of peacetime standards which are quite conservative and properly so.

Probably—it is not for me to judge, but in nuclear warfare we have some different standards. You must accept higher doses in wartime.

Of course, one of the possible solutions to this is to have an adequate supply of canned milk or powdered milk on hand, or to avoid milk which would be difficult for infants and young children.

In terms of the rest of the food supply this is pretty much a problem of surface contamination. It is not a problem of going through soils and up through the roots of the plants; it is surface contamination.

Much of the activity can be washed off, perhaps 80 to 90 percent, but in areas of heavy fallout this would not be enough in itself.

There is still enough activity left that exposed foods would not be edible. How long this is would depend on various factors, but it might be a matter of several weeks.

The decay of these isotopes is rapid after a few months and then the foods possibly would be edible.

This points up the obvious factor that in terms of preparation not only do we need shelters in this country, but we need shelters that are stocked with food supplies. We might find ourselves in one of these areas with essentially no fallout on which we perhaps wasted our money.

On the other hand, you just don't know. So in terms of the country as a whole, shelters with food supplies that will last several weeks would certainly be a commendable step.

Turning over the pages rapidly then to page 10 of my statement (p. 449), there we have discussed the doses to the gastrointestinal tract,

the stomach, intestines. Here again we find the heavy contamination would preclude the use of those foods so exposed to the fallout. We realize these are precise numbers, but they do give a feeling, an estimate, of the activity.

The radioactive fallout from 1 square foot of surface if ingested would probably result in death.

I realize people won't go along licking off the surface of 1 square foot, but it does give the feeling that the environment will be very heavily contaminated and once again pointing up to the desirability of shelters well stocked with food for several weeks.

Turning to page 11 of my statement (p. 451), we get into the production of the long-term effects of leukemia and bone tumor and we are less certain in our estimates.

One of the factors is the external gamma radiation. How much radiation will people receive? It depends so greatly on the availability of shelters and the indoctrination of the people to use those shelters. You can have estimates from essentially zero or very low numbers, up to very high numbers, depending on just those two factors.

I have suggested here that the time may come when shelters with adequate shielding properties will be built into homes. I think in a holocaust of such a war as this we will be pretty much on a do-it-yourself basis for a time; that shelters in the home will be a highly desirable thing, that these shelters should be stocked with food and water for a period of several weeks and the populace properly indoctrinated to cope with these extreme emergency conditions.

This may be true some day, but in 1959 when we are doing this exercise, my personal opinion as I have expressed here is that this is not the case.

Whether this situation of preparedness is true in Russia or not I do not know, but there is published literature that I think is very pertinent that the Russian people are receiving a great deal of instructions, but we are not so sure as to how valid it is.

The materials that I have seen, for example, have a discussion of the small yield devices such as fired at Hiroshima, but only the briefest mention as to high yield devices. Also information about fallout is given where they show a city being hit with fallout where the fallout patterns of any consequence extend only a few blocks down the city, not over the area that you have shown here.

Representative HOLIFIELD. You have seen the study made by the Subcommittee on Military Operations of the House Committee on Government Operations, have you not, Doctor?

Dr. DUNNING. Yes, sir; I found it very enlightening.

Representative HOLIFIELD. This was the first study, that was under my direction, that has been made of the available material on the Russian system. It was taken by the Russian language experts in the Library of Congress from a screening of all the documents they have been able to obtain from within Russia.

It gives, as you say, a picture which, for some reason does not use the large yield weapons in their displays, in their different pictures.

Now, whether this is from the standpoint of the psychological effect on the Russian people, or not, we cannot say. But we do know, of course, that the Soviets have tested very high yield hydrogen-type weapons, much larger than used in these pictures in their civil defense pamphlet which we have been able to obtain.

Dr. DUNNING. Turning to page 12 of my statement (p. 451), then, we have for calculation purposes said let us assume, then, that in this heavy contaminated area that survivors might accumulate five hundred roentgens exposure. This is a total exposure over a period of time, probably most of it coming the first year, most of it coming the first few months.

Then asking the question: What might be the results in terms of leukemia and bone tumor production. Using assumptions which are clearly stated and which one may discuss pro and con, the answer comes out about 3 percent of the surviving population in the heavily contaminated area that receives the 500 roentgens exposure, then about 3 percent of those people might be expected to develop leukemia or bone tumor.

Representative HOSMER. Dr. Dunning, in calculating that 500-roentgen exposure, is there some factor that you apply to the fallout environment, to calculate the dose that a person in that environment would pick up?

Dr. DUNNING. Yes, sir.

Representative HOSMER. If the level is 100, the individual in it would not necessarily pick up 100 roentgens; he would pick up something less; would he not?

Dr. DUNNING. If the level was 100 roentgens per hour you mean?

Representative HOSMER. Yes, from the fallout deposited on the surface?

Dr. DUNNING. That is right.

The actual total dose that one might accumulate depends on so many factors, such as, the availability of shelters, and whether they actually use the shelters and so forth, that one can only take a number like 500 and say this, and I feel this is perhaps somewhat pessimistic, I am sure the country as a whole will not receive it, this is to the limited area of heavy fallout, but those people, if they did not have the shelters and were not indoctrinated to use them, if they did have them, then they would accumulate something like 500 roentgens exposure.

Representative HOSMER. In other words, again it becomes a very speculative problem to see how that dose was acquired.

You have just to start out with that dose?

Dr. DUNNING. That is right.

In this heavily contaminated area one can make rough estimates of what is the total possible dose if a person stood out of doors for a long period of time, a year or two. From this you can get some feel as to what exposure one might receive.

But, again, it all depends on what he does, whether the shelters are there and whether he uses them, or not.

Representative HOSMER. My point is not directed to what he does, which is another variable, but the environment, where the roentgens would probably not produce the equivalent exposure.

In other words, if a person is walking over a piece of ground that has fallout, and he is 6 feet tall, his head is 6 feet away from the source of radiation where his feet are directly on it and so on.

Dr. DUNNING. That is right.

Moving along in haste, then, to page 14 of my statement (p. 453), the strontium 90 problem of which we have heard so much, in past

years—this is most uncertain and as some of the previous witnesses have indicated our past data on strontium 90 has resulted in more or less a continual dribble where this would be a one-shot affair with heavy contamination.

So any extrapolation would be most uncertain, but rather than throwing up our hands and saying we have no concept I think we can come up with such estimates as about 500 roentgens to the bone marrow—this is based on the worst assumption, people did nothing to decontaminate the area or to decontaminate the food, if they continue to live there and eat that food, then you might have something like 1.7 percent of the population developing leukemia or bone tumor from this cause, strontium 90.

Please do not read any precision in that 1.7. That is merely the way the arithmetic comes out.

Representative HOSMER. Is that not also disregarding weathering and other factors which we have heard so much about?

Dr. DUNNING. This is assuming no weathering, no decontamination taking place, again the worst assumption feeling that one can extrapolate from worst down rather than trying to extrapolate upward and not knowing where to stop.

On page 17 (p. 456) I have briefly indicated we have considered strontium 90 only, not the others, such as strontium 89, because in this long-term problem the other bone-seeking elements are not of principal importance.

Representative HOSMER. I wish you would answer quite plainly for the record what your calculations are on the buildup of strontium 90 globally, the global buildup, and in the United States as it pertains to this pattern of attack.

Dr. DUNNING. Yes, sir.

If I may, for a moment I would like to finish the United States and then I had proposed to show what would happen in the rest of the world.

Representative HOLIFIELD. Fine.

Dr. DUNNING. On page 18 (p. 457), is considered cesium 137, and with the same kind of calculation, page 19 (p. 458), the other isotopes, and ending off then with a total of accumulated leukemia and bone tumor production from all these causes in areas of heavy contamination, of 5.7 percent of the surviving population.

The other effect of lifeshortening I will mention briefly because of the shortness of time.

Also, I guess, because we are not very sure of how to estimate lifeshortening.

However, estimates are quoted and rounding off because in trying to strike a sort of happy medium, these doses are neither instantaneous doses as many of the experiments are or doses prolonged in time, equal doses, day by day, but rather it is heavy one at first with lesser doses as time goes on.

Representative HOLIFIELD. Will you at this point comment? I have not looked through your whole presentation but we were criticized for not going into more detail on the carbon 14 element. I do not know whether you treat it in your presentation, or not.

Dr. DUNNING. Page 24 (p. 463), in fact, we will go right to that now.

Representative HOLIFIELD. Will you state in layman's language the facts on carbon 14?

Dr. DUNNING. Yes, sir; if I may finish this last statement of lifeshortening. Our best estimate is possibly lifeshortening of 5 years.

Representative HOLIFIELD. Not that I am trying to anticipate, but I want to be sure that we get everything in your testimony because you are skipping through it.

Dr. DUNNING. For carbon 14 the calculations are on page 24 and some later on. Once again, one can discuss these and perhaps we can differ with them in some degree, but I have quoted and used the estimated calculations of Dr. Pauling and using his estimates and using the amount of carbon 14 produced in this attack, it comes out that the total radiation dose, and this includes not only radiation but other effects. That is, when the carbon 14 disintegrates it changes into another element and this causes a change as well as radiation. Taking into account the total effective dose, the total effective dose over 8,000 years from carbon 14 from this attack would amount to about 3.4 roentgens.

As I said here, during this same period of time, 8,000 years, the dose from naturally appearing radioisotopes from environment and cosmic rays might amount to 800 roentgens assuming no change in the present rate of production.

The effect of carbon 14 would not be zero, but would not constitute a problem to the same degree as the other factors.

Representative HOLIFIELD. Now, why is this true, Doctor? Is it because of the very small amount of carbon 14 that is manufactured in a hydrogen explosion?

Dr. DUNNING. This is the principal cause; yes, sir.

Based on the best information that we have, one can determine how many neutrons will appear outside of the bomb and then assuming again the worst case, that everyone of these neutrons will enter a nitrogen atom and form carbon 14, then you have a certain amount of carbon 14 produced.

That, in itself, determines your final answer.

Representative HOLIFIELD. This reading you gave is computed against 4,000 megatons?

Dr. DUNNING. 4,000 megatons; yes, sir.

I use these carbon 14 calculations also in the section on genetics. I am not a geneticist. I have used the work of Dr. Crow, applying his calculations and the answers come out that this heavily contaminated area the increased production of genetic defect would be 130 percent for the first generation. That is a factor of 1.3 or a little more than doubling, or possibly less.

As you know, the latest work of Dr. Russel suggests that perhaps there is less effective genetic defects per roentgens of exposure. So it is 130 percent or possibly less for the first generation with lesser effects with succeeding generations.

Representative HOSMER. Dr. Dunning, we have at the present time, according to your figures, about 2 percent of live births with tangible defects of the category about which you are talking.

Dr. DUNNING. Yes, sir; those are Dr. Crow's figures.

Representative HOSMER. That is attributable to natural background radiation?

Dr. DUNNING. Yes, sir.

Representative HOSMER. This would essentially add another 2 percent?

Dr. DUNNING. That is right.

Of course, in addition to radiation produced defects there are defects from other causes.

Representative HOSMER. That amounts to about another 2 percent?

Dr. DUNNING. That is right.

Representative HOSMER. So the defect rate now is 4 per 100. Under the assumption you have here, it would go 6 in a 100.

Under Dr. Russel's studies it would not go six, but it would be reduced by a factor of four, I think, which would go, the total defective work would go from four to 4.4?

Dr. DUNNING. It might be possibly as low as a factor of four below this estimate of 130 percent.

Representative HOSMER. And like extrapolations apply to other genetic effects as stillbirths, miscarriages, and so forth?

Dr. DUNNING. That is right. It applies across the board to those defects.

Lastly, on the situation outside of the United States, there is, as you well know, Mr. Chairman, a considerable discussion on the amount of contamination that would occur, and I am not talking now about fringe areas. Obviously if an area is downwind from a local fallout pattern, it is going to receive this fallout.

I think, based on the best knowledge we have today, the answer is fairly clear and I hope not too complex. It simply is this:

For detonations fired in a general latitude of the United States or Europe, the activity that comes down will center pretty much around the 45° north latitude, will spread out either side and roughly what is called the Gaussian curve, which means that about 70 to 75 percent of the total activity will fall between 30° and 60° north latitude.

That probably less than 10 percent will go to the Southern Hemisphere, the remainder being spread over the Northern Hemisphere.

Now, simple calculations then show that for the long-lived isotopes, which are the worst, that if one estimated how much strontium 90 fell out per square mile on an average in the United States and said, Well, how much strontium 90 will fall out in the rest of this band, in this most heavily contaminated band, the answer is about one sixty-fourth.

Again I don't mean to apply great precision. It might be one-fiftieth, or one seventy-fifth, but in that order.

Representative HOLIFIELD. I think it is a most important statement because it is a very significant statement. It is a very significant statement and if I understand you right, and I want to repeat it because of its importance, your statement is global fallout from an attack like this, on those countries not actually under bombardment, would amount to about one sixty-fourth of the long-range residual effect of the nation attacked?

Dr. DUNNING. That is correct.

Representative HOLIFIELD. We have seen so many statements, even recently, in the paper that this will kill the people throughout the world; that this type of attack would kill the people of adjoining nations and within the band you spoke of around the center of the earth, and according to your testimony this is not a true statement.

The global deposit would be one sixty-fourth the residual deposit of the place where the bombs were actually exploded?

Dr. DUNNING. That is right.

Representative HOLIFIELD. You further state there may be a factor of error on this, it might be one-fiftieth or some other fraction, but in the neighborhood of one sixty-fourth?

Dr. DUNNING. That is right. From the best knowledge we have today that is the way the numbers come out.

Representative HOLIFIELD. Is this a generally accepted assumption in the scientific world?

Dr. DUNNING. I was about to give due credit to Dr. Machta. I have had a great deal of help from him. We went over the past fallout data from tests and I am sure he would concur with me in this statement.

Now, whether everyone will concur, I don't know.

Representative HOLIFIELD. Did you use the global readings which we have now and relate them to the 92 megatons of fission yield which has been released in our tests, as a basis for this assumption?

Dr. DUNNING. Yes, sir; making due allowances that some of the detonations were in a rather far north latitude and some of the detonations were near the Equator because if you do get in a very far northerly latitude or near the Equator, then you do not get exactly the same distribution.

What I said was that detonations anywhere in the latitude of the United States or Europe, then you get this kind of distribution.

Representative HOLIFIELD. These new data, which show that the majority of the material does descend in the central band around the earth, what would you call it, the North Temperate and South Temperate Zones?

Dr. DUNNING. It is not exactly a temperate zone, Mr. Holifield. In fact, I said 30° to 60°. There is no sharp cutoff. The curve slopes off. It is a fairly good dividing line.

We have 70 to 75 percent of your activity falling within that band.

Representative HOLIFIELD. Colonel Lunger just called to my attention that other testimony in these hearings did use a band of 20° to 60° north latitude.

Dr. DUNNING. If you go down to 20°, then maybe you have encompassed another 5 percent, maybe it is 75 to 80 percent.

Representative HOLIFIELD. I think the testimony further stated about 70 to 75 percent of the fallout in the 30° to 60° you said.

Dr. DUNNING. That is right.

Now, please understand that the estimates I am making are not final statements. They are merely facts as we know them, scientific data.

Representative HOLIFIELD. This committee wants facts, Doctor.

Where you do not have facts, we always want it stated that it is an assumption or your best judgment based on the information you do have.

I think you have qualified your statement all the way through in proper fashion.

Dr. DUNNING. Most of these facts have a great deal of judgment in them, sir.

Another effect is iodine worldwide contamination. Because iodine is a short-life isotope even less will come down than in this factor

of one sixty-fourth, a rough guess would be one six-hundredth, from the country receiving the attack.

If I may show one chart I have tried to summarize my information on some biological effects on survivors living within the United States and again reminding you this is a heavily contaminated area. There will be segments of the country where there essentially is no contamination and all those values then will become essentially zero.

We see leukemia and bone tumor 5 to 10 percent. The numbers came out 5.7 but I gave it a range of 5 to 10 again as an upper limit.

Now, as to the cancer or serious malfunction of children's thyroid, this is very dependent on what people do in the United States.

In this heavily contaminated area if they were to drink the milk and eat the food without washing it and took no protective measures, then you might get a high percentage of the children showing up with this effect.

On the other hand, of course, the corollary is equally true with precaution this can be reduced.

Life shortening of 5 years, genetic defects 130 percent or less—that is in the first generation and so beyond that, in succeeding generations, there will be lesser effects.

Outside of the countries attacked and I do not mean the fringe areas, but generally in the 30° to 60° north latitude, leukemia and bone tumor 0.014, or it may be zero.

As you know, there are discussions concerning threshold effect, or nonthreshold, and these doses are so low that they may be zero effect.

I think the actual doses come out in the order of one or two roentgens. There may be no effect.

Again, as an upper limit, we have 0.014 percent. For the cancer or children's thyroid it is uncertain.

By that I mean according to the calculations if people did nothing, drank the milk, then children might receive 600 to 1,200 rad dose to the thyroid, but with due precautions, eliminating milk from the diet for a few weeks, substituting clean foods, then value could go down to a low figure.

Lifeshortening becomes very difficult to estimate, getting down to the order of one to two rad dose, for a few to several days.

Genetic defects again using upper limits—0.3 percent or less, for the first generation and less effect in succeeding generations.

Representative HOSMER. In other words, the figures you have on your table there are again the absolute maximum figures, assuming that little or no precautions are actually taken?

Dr. DUNNING. With one possible exception. It is true in some areas of the world, where they have other than milk as their main source of intake of calcium such as in the Far East, then you may have a higher number for the leukemia and bone tumor production.

If there is a threshold, then again there their numbers would come out essentially zero, also.

If there is a threshold, then that value of 0.014 might go up to 0.048 percent.

Representative HOSMER. That is because of the high percent of calcium or what.

Dr. DUNNING. There is less discrimination against strontium when the calcium comes from other foods than milk.

Representative HOLIFIELD. In the Far East they depend on rice and other vegetables for their calcium to a greater extent than we do in our country.

Dr. DUNNING. That is right.

Senator HICKENLOOPER. What does the column "Genetics effect within the United States 130 percent or less" mean?

I say, What does 130 percent or less mean? One hundred percent is about as much as you can get, is it not?

Dr. DUNNING. If it were 100 percent it would mean that all defects that we now see today caused by natural radiation would be doubled. This 130 percent means a little bit more than doubled.

Senator HICKENLOOPER. That means at present the 130 percent applies to existing conditions?

Dr. DUNNING. That is right.

Representative HOSMER. Applies to the 2 percent figure we now have?

Dr. DUNNING. Yes, then one has to say what is the natural rate. As you have seen in the testimony, for tangible effect 2 percent due to radiation and another 2 percent due from other causes.

Representative HOLIFIELD. Again that 2 percent that is ascribed to radiation is a percentage arrived at by prudent judgment rather than by laboratory proof, is it not?

Dr. DUNNING. I would think probably it is both laboratory experiments with animals, but certainly judgment.

The National Academy of Sciences report which describes this in some detail, I think makes full qualifications as to their judgment on this.

Representative HOLIFIELD. We have had testified many times before this committee that the natural radiation level of dose is not great enough to prove damaging to genes. They have to use a higher dose rate in order to observe meaningful laboratory results or damage and thereby obtain meaningful statistics. Is that or is that not true?

Dr. DUNNING. I do not think they meant that natural radiation will not cause genetic defects.

Representative HOLIFIELD. I am not trying to say that either. I am saying that the rate of natural radiation is so low you could not take that same rate on any kind of animal in a laboratory and cause detectable and meaningful mutations?

Dr. DUNNING. I would prefer other witnesses more qualified than I, Mr. Holifield, to answer that.

Representative HOLIFIELD. At least that is my understanding of the testimony we have had from geneticists. This does not necessarily mean that it does not cause mutations just because they cannot prove them in the laboratory. They have gone into this threshold and nonthreshold argument. Then, if the threshold does exist, it does lead to mutations.

If it does not exist, it is doubtful whether this low rate dose produces mutations.

Representative HOSMER. Dr. Dunning, if Dr. Russel's study is correct, what would the 130-percent figure be?

Dr. DUNNING. I don't think they are fully completed yet, but it suggests you might take that 130 and divide it by as much as a factor of four.

Representative HOSMER. It would be about 32½?

Dr. DUNNING. That is right.

Representative HOSMER. The figures are applied to the 2 percent figure that we have?

Dr. DUNNING. That is right.

It would be one-third times 2 percent in addition.

Representative HOLIFIELD. Are you familiar, Doctor, with the genetic studies on fish by Dr. Samuelson of the University of Washington?

Dr. DUNNING. No, sir; only in general.

If I may say again, I am not a geneticist, sir, and I would prefer others to answer that.

Representative HOLIFIELD. Are there any further questions?

Senator HICKENLOOPER. Dr. Dunning, you have taken some very serious dose rates here, have you not?

Dr. DUNNING. For the United States we have taken almost the most heavily contaminated area.

Senator HICKENLOOPER. Pardon?

Dr. DUNNING. We have taken, as an example, an area that is almost the highest in terms of contamination.

Senator HICKENLOOPER. So that the illustrations you have given here this morning could be described as being illustrations of what could happen under almost the worst possible conditions; is that true?

Dr. DUNNING. Yes, sir.

Senator HICKENLOOPER. If conditions did not turn out to be as bad so far as intensity of poisonous materials of all kinds, then the figures would be less than that?

Dr. DUNNING. That is correct, sir, all the way to essentially zero.

Senator HICKENLOOPER. So what you are saying here is that these results are not necessarily results that would occur from just any atomic attack per se; is that correct?

Dr. DUNNING. That is correct. I hope I have qualified my statements at the beginning and all the way through, that this refers only to this limited heavy area, because from this one can extrapolate downward much easier than if you take another area and tried to extrapolate upwards.

Senator HICKENLOOPER. Of course, our concern is the many cases of misinformation that get out that excite the public unduly, that cause them to get a completely false impression as to the actual potentials.

Now, manifestly, a person in the area of a high explosive shell is going to get killed. There seems to be a tendency throughout the country to exaggerate the worst possible results that might occur.

I am very interested in your statement about the Russian information to their people. We have news media of various kinds that get all of this information and report it in various degrees, interpretations, and so on, to the American people, one must assume. It is testified to.

Do you know any means by which the Russian people can get the true picture of what might happen to them in case of an atomic attack?

Dr. DUNNING. No, sir; I don't know how we can do it.

I can give a personal opinion as to its desirability.

Senator HICKENLOOPER. Do you agree it would be highly desirable if the Russian people could have it thrust upon them what the results of an atomic attack would be in their own country?

But we do not seem to be able to get that across. We only seem to be able to get out to our own people what would happen to us in case of atomic attack.

The other fellow does not seem to get very much concerned about what would happen to him, which has something to do psychologically with attitudes toward international association, I am afraid.

Thank you very much.

Representative HOLIFIELD. Thank you, Dr. Dunning.

Dr. DUNNING. Thank you.

(The complete formal statement of Dr. Dunning appears starting on p. 436.)

Representative HOLIFIELD. Our next witness is Mr. W. E. Strope, National Radiological Defense Laboratory.

He will speak on survival measures.

Representative HOLIFIELD. Mr. Strope, we are glad to have you back again. You testified for our committee before. We will be glad to hear from you at this time.

STATEMENT OF WALMER E. STROPE,[1] HEAD MILITARY EVALUATIONS DIVISION, U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

Mr. STROPE. Thank you, Mr. Chairman and members of the committee. Prior testimony has established the dimensions of the attack under consideration and the number of casualties that might be expected. It is my purpose to summarize the possibilities of defense against this threat with emphasis on the problem of protection against radioactive fallout.

I propose to start by indulging in a little survival arithmetic in order to illustrate the nature of the defense problem. I have taken here (fig. 1, p. 683) initially the heavy fallout area, approximately 3,000 r/hr at 1 hour.

In this attack approximately 20 percent of the population was in a region of this level. On the other hand, 80 percent are not in so serious a condition. I will cover them shortly. But let us consider the heavy fallout area and what the nature of our problem is.

In this area the dose during the first year—this is without countermeasures, simply in the open—is approximately 12,000 roentgens. This, of course, is more than is necessary to kill a person.

Now of this first year's dose—which is the only period that we will consider, because the doses in subsequent years are so very much smaller they can be neglected in this argument—the dose in the first 2 weeks is about 10,000 roentgens.

[1] Born in Mason, Mich., Apr. 9, 1918; married, 2 children; BS, Webb Institute of Naval Architecture, 1942; engineer, Bureau of Ships, Washington, D.C., 1942–48; head, Military Evaluations Division, USNRDL, 1948 to present. AAAS; ORSA. Navy Distinguished Civilian Service Award, 1957, for contribution in field of atomic defense.

This suggests if you have a good defense during the first 2 weeks you have dealt with a very large part of the problem. This is true. On the other hand, the difference between these 2 numbers is 2,000 roentgens, and this is the exposure in the open that would be expected between 2 weeks and a year after attack.

In other words, if you were to stay in a shelter for 2 weeks and then come out, this 2,000 roentgens is what faces you during the remainder of the first year.

Now the 2,000 roentgens is the threat that we perceive in what we call the operational recovery phase of radiological defense. On the other hand, the 10,000 roentgens is the threat we perceive in the emergency phase of the problem.

Our studies at the Naval Radiological Defense Laboratory have convinced us that the central countermeasure during the emergency phase is adequate shelter. We might consider for a moment what might constitute adequate shelter in this situation.

Let us start out by considering a shelter that would provide a factor of 10 reduction in the dose. This is the sort of protection one would expect in a home basement. The dose in that sort of shelter during the first 2 weeks would be a thousand roentgens.

What have we accomplished? Essentially nothing, because during this short span of time a thousand roentgens is as lethal as 10,000 roentgens. Therefore, a factor of 10 shelter is simply not good enough.

Next let us consider a shelter having a factor of a hundred reduction. The dose in the shelter during the emergency phase—the first 2 weeks—would be approximately 100 roentgens. Now things start to get interesting. One hundred roentgens is a dose which one would not expect to produce death or even sickness. Therefore, a factor of a hundred shelter starts to look quite promising.

On the other hand, we must remember that once we come out of the shelter we have the problem of operational recovery to face and, while we may have defense measures to modify this problem, nevertheless 100 roentgens is a rather heavy burden to take into the ensuing phase. In many circumstances then one might consider that a factor of a hundred in shelter was not good enough either.

Now let us consider if we could provide our population with shelter having a factor of a thousand reduction. The dose in the emergency phase would then be 10 roentgens. This is a quite nominal exposure and for practical purposes could be ignored in dealing with the later phase.

There are apparently very few existing structures in the country that provide a factor of a thousand. So when we are talking about this sort of protection we are talking about building shelters.

Representative HOLIFIELD. Will you relate, as you did in the first instance to the ordinary basement the other two factors there, particularly the factor of a hundred?

What type of shelter would that be?

Mr. STROPE. You could get this in a large building. Certainly many areas of this Capitol Building. This is the Macy's basement type of shelter, we might say. I will discuss this somewhat later. There are a considerable number of existing structures that would supply this protection.

But there would be only a few that would provide a factor of a thousand reduction and certainly not enough to protect many people. So we are building shelters here. As long as we are building shelters, we might consider whether we might not make them even better than that.

So why not consider giving them a 10,000 factor of reduction? What have we gained by this? Essentially nothing, because one roentgen is biologically like 10 roentgens in the same sense that 1,000 roentgens is like 10,000 roentgens at the other end of the scale.

Of course, there are some small gains in going that far because there may be areas which are at a level very much above 3,000 r/hr at 1 hour. Certainly it would involve a very small fraction of the population. Thus, in general, one can say that a factor of a thousand reduction in this situation is adequate and that the gain from making shelters better than this is marginal.

Now let us turn to the operational recovery phase. This is the post-shelter problem.

Representative HOLIFIELD. Before you leave that, are you going to get to the type of shelter?

Mr. STROPE. Yes, sir; later.

Representative HOLIFIELD. All right.

Mr. STROPE. Let us consider that we have techniques for reducing this problem by a factor of 10. Our opinion is that the countermeasure that can do this is reclamation.

Let us assume we have a factor of 10; then the dose in the post-shelter period is 200 roentgens. Again, this is an interesting number. This is not a number for which we would expect lethality; we might expect some sickness. If we combine this with very good shelters, a factor of a thousand, we would have over the first year approximately a 200 r. dose to people in this area.

If we were content with a factor of 100 shelter, the dose would be of the order of 300 roentgens.

Let us consider methods of dealing with the operational recovery problem that would give us a factor of 100. In this case, we have 20 roentgens in the post-shelter phase, which again is a nominal dose, and we need not concern ourselves very much with it.

Now one of the interesting points is the interaction between these two phases. If you could assure yourself in the operational recovery phase of a reduction factor of 100 so that the dose there would be nominal, you would be much more encouraged to use less effective shelters in the emergency phase.

This suggests that it may be desirable to encourage research in this area toward better recovery performance with the objective of saving more money in terms of shelter construction.

As I said, we believe that the central countermeasure in the operational recovery phase is reclamation. Before I talk about what I think we can do in reclamation, we might discuss very briefly the other alternatives one might have at hand.

One of the alternatives would be to stay in shelter longer, particularly if you have good shelter. In order to reduce this potential 2,000 roentgens to 200 roentgens by staying in shelter longer, one would have to stay in shelter approximately 6 months, rather than 2 weeks. Shelters that would permit the population to live for 6 months are

apt to be very costly and perhaps we might consider other alternatives, such as reclamation, as preferable.

Another alternative would be to move the population in this area from shelter after about 2 weeks to areas of the country that have been spared fallout. Now, in this attack, there are large regions of the country which are essentially fallout free. They happen to be largely desert, mountain ranges, and plains. The problem of subsisting and housing a large number of survivors in this area would be a very great effort.

Actually, these two alternatives of staying in shelter for a long time or getting out of the contaminated area for a long time are not very satisfying, because we are really interested in more than a safe area for the population. We are interested in reviving the economic and political life of the country and in bringing the war to a successful conclusion.

This means that we need to regain our surviving factories, political instruments, schools, and so forth, and safe living areas associated with them. Reclamation is essentially the only tool that will do this sort of job.

A large part of the research work on reclamation has been done at the Radiological Defense Laboratory. We believe that today, using commonly available equipment and with some training, that a factor of 10 could be achieved.

Experimentally, we have actually achieved a factor of 100, but we have doubts as to whether this sort of performance could be achieved in practice. It is this sort of experimentation that might lead to a more satisfactory solution in terms of shelter.

Now turning to the second chart (fig. 2, p. 684), and still discussing the heavy fallout area, I have summarized a number of radiological defense systems which I have already discussed and what their outcome is.

First of all, we might stay in shelter a long time, 6 months. And then not attempt any recovery. If we were in fact in a factor of 100 shelter, the dose would be slightly over 300 roentgens. If we had better shelters, we would come down to about 200.

However, the only way of reducing the exposure in the first year below 200 roentgens is to either stay in shelter the whole year or reclaim in this area. Figure 2 also shows some combinations of 2-week shelters and reclamation. One can see that the sort of reclamation we believe can be done today effectively reduces shelter stay from 6 months to 2 weeks. With reclamation we think we might be able to bring about, we can get exposure for the first year very much lower.

This discussion has considered the heavy fallout area in which approximately 20 percent of the population is located in this attack. We have to consider that most of the people will not have so serious a problem. The justification for talking about countermeasures, using the heavy fallout area, is that you do have a number like 20 percent of the population involved; and generally you cannot predict which 20 percent of the population is going to be in this situation. You cannot predict the heavy areas of fallout in advance and therefore, unless you are prepared to sacrifice this 20 percent of the population, then you must consider protection at this level for virtually everyone.

At the same time, we must remember that most of the fallout areas will be subjected to a lesser threat. Let us go down to a fairly low level from our point of view, 300 roentgens per hour, a factor of 10 lower. One can easily see from the first chart that now our emergency phase problem is only 1,000 roentgens. That is still serious. The potential dose in the operational recovery phase is only 200 roentgens. A factor of 10 shelter, the home basement type reduces the emergency phase dose to a hundred roentgens. A factor of 100 shelter gives you a nominal exposure.

As a matter of fact, when the level of fallout gets below approximately 100 roentgens per hour, the need for a formal radiological defense system disappears. It is essential only for people to stay indoors for the first few days. It is very difficult for people to get killed by anything they might do in this region.

We have a continuous gradation of exposures within this range of 300 to 3,000 roentgens per hour at 1 hour. A little later I will show you what the defense problem looks like in this attack in terms of the fraction of the population involved.

Now I have noted that shielding afforded by existing buildings and other structures may afford effective protection, particularly in the light and moderate fallout areas. The number of shelter spaces that might be available in locations offering a shielding factor of 100 is not known, because techniques for making such assays have only recently become available. The actual process of looking at the structures and determining what sort of protection is available is not yet underway.

It is almost certainly true that most buildings that offer good fallout protection are also located in areas that would be concerned with blast and fires. Out in the region where only fallout is of concern, these types of buildings are much rarer. So estimates of the fraction of the population that can be afforded various levels of protection in the existing structures of the country are somewhat arbitrary at the present time.

Even where good fallout protection can be identified with existing structures, it cannot be assumed that this protection is available without cost. Such areas must be occupied for several days or weeks. Although it may be possible for people to survive without food or water or sanitary facilities for some period, generally these facilities would have to be provided. It is also generally true that such areas are not adequately ventilated for shelter use. Unless one restricts the number of shelter occupants to those that could be maintained in a habitable environment with existing ventilation—which is unlikely, considering you will have very few of these areas—then additional ventilation facilities will be required.

The Rand Corp. has estimated that it would cost $25 to $35 per person sheltered to convert a mine to a usable shelter. My own experience in shelter design leads me to approximately the same number for converting any existing structure into a usable personnel shelter.

The fact that there are probably insufficient good fallout shelters in existing structures to house the population, together with the fact that better protection than is provided by existing structures may be necessary, has placed emphasis on the problem of building shelters specifically for the purpose of protection against fallout.

Concern with the design of fallout shelters is of fairly recent origin. Virtually all tests of shelters at nuclear weapons tests have been concerned with blast protection, it being assumed that a satisfactory blast shelter will be completely satisfactory for fallout protection.

Yet little attention has been paid to the effects of entrance and ventilation openings on shielding, the requirements for ventilation during fallout, and the requirement for habitability under extended occupancy conditions.

In Operation Plumbbob in 1957 our laboratory was afforded the opportunity to participate in the civil effects test group program in this field of fallout shelter design. I was project officer on a project sponsored by the AEC that investigated some of these matters by occupying an experimental shelter at a close-in location relative to several nominal yield detonations.

The shelter we used was a buried ammunition storage magazine that had been shown in previous tests to offer very good blast protection at a comparatively low cost. I have with me a very short documentary film of one of the runs in that experimental shelter during Operation Plumbbob.

If the committee please, it will be shown.

(Film demonstration.)

Senator HICKENLOOPER. How do you operate the blowers?

Mr. STROPE. There was an auxiliary power room buried just off the entrance.

Senator HICKENLOOPER. Did you use a gasoline engine?

Mr. STROPE. Yes, sir.

Following this operation, a design study was undertaken based on what we learned in this operation in which we attempted to design a satisfactory fallout shelter at minimum cost. In this study, which is now completed but not yet published, we proposed a set of minimum performance specifications for protection, access time, habitability, and the like. We then designed in detail a shelter meeting these specifications based on the same ammunition storage magazine which you saw in the film.

I have a sketch on the next chart (fig. 3, p. 689) of the particular shelter that resulted from this study. It differs in considerable detail from the one at the test at Nevada, because it incorporates many of the things we learned there.

Senator HICKENLOOPER. Regarding ventilation, did you bring the air in from the outside and circulate it through and blow it out, or what?

Mr. STROPE. The air came down the entrance tunnel, through ventilators at the door.

Senator HICKENLOOPER. Did you have trapping devices to keep fallout from being blown in?

Mr. STROPE. You mean filters? We did, but this was because we were trying to find out how much would come in. Filters were one of the experimental techniques for determining this. The results were such that we could discern in that operation no requirement for filtration of air in the shelters.

Actually, there are some unanswered questions about this because the type of weapons that are detonated in Nevada are not the ones that we are talking about in this hearing, nor are the burst conditions, soil, and so forth, the same.

So that in this design I am now talking about, we offer as alternatives, either filtered or unfiltered air, and we cost the alternatives so that one can determine what it costs to filter air for a shelter of this type.

That is, within the basic specifications we considered a number of alternatives in almost all design areas. We considered alternatives in respect to the degree of austerity in living accommodations, comfort in the shelter environment and the like.

We attempted in each one of these cases a detailed estimate.

This procedure gave us not only an estimate of total shelter costs, but also some understanding of the cost of making people comfortable, of providing filtered air, of providing increased blast protection, and of providing various levels of creature comfort in living accommodations.

The results indicate that we should be able to provide adequate fallout shelters of this type with a shielding factor of at least a thousand for approximately $100 to $125 per person sheltered.

Representative HOSMER. At 100 to 125?

Mr. STROPE. That is right.

Representative HOSMER. That is an amazing figure when related to something else. I think it should be.

We are spending about $6 billion on farm subsidy programs a year. For that $6 billion you could provide 60 million shelter spaces with a factor of a thousand protection, which amounts to 1 million spaces more than the total casualties killed and injured in the hypothetical example we had earlier today.

Mr. STROPE. Yes. I will discuss program costs in this presentation.

Representative HOSMER. I know what I would spend my money on if I had my choice.

Mr. STROPE. These shelters we are talking about will also provide protection against blast overpressures up to 10 p.s.i. It is anticipated that buried shelters of this type could be placed in groups under school playgrounds, in parks, and in storage and parking areas in industrial plants and the like.

I might say that this is not a shelter that conveniently goes into the very highly built up downtown sections of a city.

We also found out in the study that insufficient information exists on a number of subjects that are essential to the efficient design of fallout shelter. Based on a review of the preliminary draft of the report the Office of Civil and Defense Mobilization has requested that the laboratory construct a prototype shelter of this type and conduct the necessary experiments to resolve the questions we have raised. This prototype shelter is under construction now at the Park Air Force Base near Livermore, Calif., and we expect to start experiments early in August.

We will get some additional insight in the problem of shelter costs in building this shelter. The shelter tests will include studies of the environment inside the shelter using heat and moisture sources to simulate the shelter occupants.

We will also study the shielding provided by the newly designed entrance.

We will also study the problem of the ingress of fallout particles into the shelter. This is the question of the filtration of air.

Ultimately it is hoped to prove-test the shelter by occupying it for a 2-week period with the full complement of 100 persons.

The end result will be the first fully tested design of a high performance fallout shelter available in this country.

Now, I would like to turn to the postshelter problem of recovering the use of essential facilities needed to reconstruct the economy. I would like to expand briefly on my previous statement that we think we can get a factor of 10 reduction at the present time. This statement is based on a considerable history of experimentation beginning with Operations JANGLE in 1952, and more recently field experiments have been conducted at Camp Stoneman in California, using simulated land fallout. Work of this type will continue under OCDM sponsorship at Parks Air Force Base. Areas of this base, which is being turned over to the Army shortly, have been set aside for USNRDL research work.

The principal weakness in present knowledge in reclamation stems from the fact that no experimental reclamation of actual facilities such as industrial plants, oil refineries, residential areas and the like, has actually been accomplished. All of our previous studies have been confined to typical elements such as streets, roofs, and so forth. Experimental decontamination of complex target facilities are planned for the near future. The results should indicate to what extent the effectiveness we have seen on typical elements, that is, a reduction factor of 100, can be expected in real situations.

The work should also result in well-designed procedures that can be used to train recovery crews on a countrywide basis. Meanwhile, we are estimating for OCDM, based on our present knowledge, the effectiveness and cost of reclaiming specific facilities considered essential for post-attack recuperation of the economy.

Now, continuing consideration of the fallout problem, I would like to consider the effects of various levels of protection on the human casualties caused by this particular attack for the committee. One of the difficulties here hinges on the definition of the term casualty. One interpretation might be whether a person lives or dies during the attack period. On the other hand, some criterion of injury might be selected that would consider either radiation sickness or the longer term effects that have been discussed in prior testimony, perhaps even genetic effects.

I shall avoid an arbitrary definition of radiation casualty by presenting calculations for this attack showing the fraction of the total population receiving various radiation doses, these doses being ones that might be used to define a casualty.

In making these calculations I consulted Dr. Joseph Coker, who is director of the National Damage Assessment Center, and who actually ran these calculations, and obtained an estimate of the fraction of the population located in areas that received various levels of fallout.

Using this information I obtained the results shown in my last chart (fig. 4, p. 692).

In the body of the table are the percentages of the total population of the country that would be found in various conditions. The table is broken into two parts. First the dose in the first 2 weeks is shown. This is the emergency phase and this is where the question of living and dying is decided in the main.

I have also parallel to it the dose in the first year and this is the problem of the longer term effects mainly.

For each of these time periods, I have shown the fraction of the population that will receive less than 50 roentgens, less than 150 roentgens, less than 600 roentgens, and those that will receive more than 600 roentgens.

Now, one unwarranted scare headline in this chart which I would like to avoid is concerned with the first line which is labeled "Unprotected." By this I mean precisely that, unprotected. This means that your whole population is standing out in the middle of a field. These numbers then do not represent the real world because there is a certain amount of protection afforded in the normal envioronment. This shows an upper limit and it shows roughly 70 percent of the population dead from the exposure in this situation.

Representative HOLIFIELD. That is 70 percent of the population that has been exposed?

Mr. STROPE. No, sir.

Representative HOLIFIELD. Seventy percent of the total population?

Mr. STROPE. That is correct.

Representative HOLIFIELD. In the United States?

Mr. STROPE. That is correct.

Let us look at the next line, which is the most primitive defense system I have considered, namely, a factor of 10 reduction shelter and no reclamation in the ensuing period after 2 weeks.

You can see the big difference. Now only about a quarter of the population is over 600 roentgens.

I am sure that in the casualty estimates that were given this morning consideration was given to the sort of shelters that people might have today and I would suspect, since I do not believe that all of the population could be afforded a factor of 10 reduction in shelter, that the casualty figure should lie between my first two estimates.

Actually, the number given this morning is about 25 percent of the population dead from all causes, which, accounting for the overlap of blast and thermal effects with the fallout effects, does not seem to be large enough. So that perhaps there is a difference in the way these two estimates are calculated.

I believe the calculations that were done this morning were based, for example, on the $t^{-1.2}$ rule. My calculations are not based on this, but are based on the type of data that have been discussed by previous panels.

Representative HOLIFIELD. What is the formula?

Mr. STROPE. There is no formula. It is an actual decay curve. We use a set of dose multipliers to make calculations, as there is no equivalent to the $t^{-1.2}$ relationship.

Representative HOLIFIELD. What is the difference?

Mr. STROPE. The details of this, Mr. Chairman, were presented at the 1957 fallout hearings. They are in the record. In general, in comparison with the 1.2 rule the doses in the first week are much higher. By much, I mean a factor of 50 percent to almost 100 percent and after about several months the decay rate is much steeper.

So the hazard at later times is much less than you would expect from the $t^{-1.2}$ rule.

Representative HOLIFIELD. That sounds like the 2.7 formula.

Mr. STROPE. At a later time you might find this.

Representative HOSMER. Can you apply those figures to the casualties this morning and come out with anything reasonable?

Mr. STROPE. If you assume that 450 roentgens is the mid-lethal exposure, yes.

The chest gives the dose for the first 2 weeks, but a large portion of this exposure is in the first few days so that perhaps all of those people receiving our 600 roentgens should be counted as deaths.

What fraction of those receiving below 600 but above 300 roentgens will die is not easy to estimate. It is certain that some of them will die. My estimate for the completely unprotected situation is of the order of 70 percent deaths.

Representative HOSMER. You have it down to 23 by your most minimal protection?

Mr. STROPE. That is right.

Representative HOSMER. Roughly you cut it down two-thirds?

Mr. STROPE. That is right.

Representative HOSMER. I am just wondering with the 19½ million casualties we were talking about this morning, would you cut this down to one-third or roughly 6 or 7 million?

Mr. STROPE. You mean the total casualties? Let me discuss that in just a moment.

Representative HOLIFIELD. Will you tell me which line represents the type of shelter you tested in Nevada?

Mr. STROPE. The bottom two lines utilize the shelter we tested in Nevada. What it says is that we do not expect anybody to come out of that shelter at the end of 2 weeks with a dose exceeding 50 roentgens in this attack.

Representative HOLIFIELD. I do not quite understand the 100.

Mr. STROPE. That means that 100 percent of the people have an exposure less than any number up there. In other words, there is nobody that exceeds 50 roentgens.

Representative HOSMER. You could put it the other way around. Where the 100 is you can say zero percent received that many?

Mr. STROPE. That is right.

Representative HOLIFIELD. Then what type of shelter is the fourth line from the bottom, because there, again, you get a zero?

Mr. STROPE. Zero for over 600. That is your Macy's basement type, a factor of 100.

You will recall that we showed that a factor of 100 in the high levels would give you only a 100 roentgen dose. So you would not expect any deaths even with the factor of 100 shelter.

Representative HOLIFIELD. How would this compare with the basement-type shelter contained in the OCDM pamphlet?

Mr. STROPE. I have not seen this. I have been told they have been designing for a reduction factor of 250 or 500.

Representative HOLIFIELD. I wonder if Dr. Shafer is present and has that pamphlet so he can bring it forward at this time.

Mr. STROPE. It appears that it lies between these two systems.

Representative HOLIFIELD. Between the 71 and 100?

Mr. STROPE. Yes.

In other words, the OCDM shelter is better than a factor of 100 and not quite as good as a factor of a thousand.

Dr. SHAFER. The number is 250 or 500 depending on the type structures.

Mr. STROPE. Then we have said the right thing. So that the protection requirement there is a good protection requirement.

Representative HOLIFIELD. That cost, Dr. Shafer, was what?

Dr. SHAFER. $150 to $175 for materials. This is a do-it-yourself type.

Mr. STROPE. Of course, you realize that home shelters, small shelters in general, are relatively more costly than when you group people together as they have been in the shelter I have discussed.

Representative HOLIFIELD. The figures you are giving on protective shelters certainly indicate that it is within our technological and economic capability to give the people of this country reasonable protection outside of the immediate blast crater area.

Mr. STROPE. Yes. I think that any shelter that offers a factor of 100 to 1,000 is a good fallout shelter.

Suppose on the one hand it was decided not to build any new shelters, but we would try to shelter our population in existing buildings, tunnels, mines and the like, carefully selecting the best locations we could find for this purpose. Assuming we need approximately 200 million shelter spaces and it would cost about $25 a person to outfit that space and provide minimum ventilation and so forth, such a course of action would entail an expenditure of approximately $5 billion for 200 million shelter spaces.

If on the other hand it is decided to build a system of fallout shelters of the type that I have described here, it would cost about $20 billion.

Another course of action which has considerable merit—that is it has merit to me; let me put it that way—would be to exploit the best protective locations in existing structures, only those that have better than a factor of 100 and to supplement these as necessary with new construction of the type I suggest.

The cost of such action would lie between $5 and $20 billion and would depend to some extent on what fraction of the population could be sheltered in existing structures.

Representative HOSMER. Those figures are based on protecting the whole population?

Mr. STROPE. I am talking about 200 million shelter spaces, a mix, if you like, of existing structures at $25 a head, and new shelters at $100 a head.

Now, the dollar cost of reclamation is very small. The principal problems are ones of organization and training. There are post-attack costs of manpower and materials and radiation dose that will constitute a demand on the surviving resources. But for purposes of assessing costs of preparing defense I think the cost reclamation may be neglected.

Therefore, in summary, I would say the principal cost of the radiological defense measures that appear essential to national survival will be those attributable to provision of adequate shelter and these costs would lie in the range of $5 to $20 billion depending on the amount of existing structures that will be useful.

Now, I have skipped over one item which I would like to mention. I have been talking about fallout completely. It appeared this morning from the casualty estimates that blast and thermal would have killed some 31.2 million people in this attack, or roughly 20 percent of the population or thereabouts.

Therefore, while we can talk about fallout protection in which nobody gets more than a small exposure from the direct fallout, nevertheless, in the overall picture you will never be able to reduce your casualties below the figure quoted this morning for this attack as resulting from the blast and thermal effects.

I mentioned that this underground shelter was capable of withstanding 10 p.s.i. blast overpressure. If it also is provided with protection against firestorms, which is also a package in this design, then the casualties from all effects could be limited to about 8 percent of the population in this attack.

This can be compared with the 20 or 25 percent killed that was mentioned this morning. We would get it down to 8 percent.

Representative HOLIFIELD. In other words, we could save two-thirds by an expenditure such as you offer.

Mr. STROPE. Yes.

Representative HOSMER. You would have only one-third of your casualties?

Mr. STROPE. That is right.

Representative HOSMER. That applies pretty well to the factor you are talking about over there.

Mr. STROPE. We are down to 8 percent of our population now. This same shelter can also be designed to resist higher pressures. Thirty-five p.s.i. blast overpressure protection could be provided at an increase in cost of not more than 50 percent per person sheltered. This would bring the cost of the shelter to around $175 or so.

If you provided that type of shelter, particularly in the urban areas where blast and thermal effects could be expected, the total casualties in this attack would be reduced to approximately 3 percent of the population.

If you want to protect that 3 percent you must go to deep underground shelters and a much more costly program.

Now, there is one warning on this, that these estimates assume that the people are in the shelter at the time of attack; they get warning. The same requirement does not exist for fallout shelter since there is sufficient time between detonation and arrival of fallout to take shelter. That concludes my statement, Mr. Chairman.

Representative HOLIFIELD. Your conclusion must inevitably be, then, that if we put any worth at all on human lives we can save by the expenditure of less than $20 billion, we could reduce the numbers killed in this type of attack from over 30 percent to down around 3 percent?

Mr. STROPE. Not the numbers I quoted. Down to 8 percent for the numbers I quoted.

Representative HOLIFIELD. Down to 8 percent?

Mr. STROPE. Yes.

Representative HOSMER. It certainly would be a dulling factor of an enemy's objective.

Mr. STROPE. I believe this.

Representative HOLIFIELD. Congressman Hosmer spoke of the cost of our surplus crops. I want to relate it to the cost of our annual military expenditures which run 40 or more billion dollars a year. This would be approximately one-third or not quite one-half.

Mr. STROPE. The 60 percent of the population of the country that resides outside the urban areas and have only fallout as a threat can be protected at a fairly modest cost, so modest in comparison with typical other expenditures that I do not see why anybody should die of fallout in an attack of this type and if in future attacks they were to do so, I would tend to lay the cause to penury rather than to fall-out.

Representative HOLIFIELD. The fatally injured from fallout in the assumption pattern analysis is 10.7 million people and the surviving injured is 10.9. All of them would be theoretically safe if they were in the shelters?

Mr. STROPE. If they were in shelters I have shown, not only would they be saved, but a considerable group of those that are labeled blast and thermal casualties would also be saved because of the protection factors afforded.

Representative HOLIFIELD. 6.3 million. The 17.2 million in the chart labeled "surviving injured" would definitely have almost 100-percent opportunity. A great many of those fatally injured in the 22.2 would also have that factor of protection.

Mr. STROPE. Yes, sir.

(The complete formal statement of Mr. Strope follows:)

Survival Measures

by Walmer E. Strope

Previous testimony before this committee has established the dimensions of the casualty-producing potential of a massive thermonuclear attack on the United States. It is my purpose to summarize the possibilities of defense against this threat, with emphasis on protection against radioactive fallout.

An understanding of the problem of defense against fallout can be gained by the use of some "survival arithmetic." Consider the threat associated with the region of heavy deposit of fallout; say, those areas experiencing a level of 3000 r/hr at 1 hour. Under the attack conditions specified for these hearings, about 20 percent of the population would be in such areas. The radiation dose in the first year to unprotected persons for this condition would be approximately 12,000 roentgens.* (The dose during subsequent years would be quite small and can be ignored for our purposes.) Of this 12,000 roentgens dose, approximately 10,000 would be received during the first two weeks after the attack. This suggests that if very good protection were available during the first two weeks, much of the fallout threat would be vitiated.

Although this is true, it is also true that the difference between 12,000 roentgens and 10,000 roentgens is 2000 roentgens. This large dose, which is delivered between 2 weeks and a year after attack, cannot be

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* All calculations are based on reference 1.

ignored. It constitutes the threat during the operational recovery phase of radiological defense. (See Figure 1.) On the other hand, the dose during the first two weeks, 10,000 roentgens, constitutes the threat during the emergency phase.

Our studies at the Naval Radiological Defense Laboratory have led us to the conclusion that adequate shelter is the central countermeasure during the emergency phase of radiological defense. Let us consider what constitutes adequate shelter in this situation. It is clear that the small amount of shielding afforded by private homes would not be sufficient. Suppose we could place our population in areas that reduced the exposure by a factor of 10. Home basements give this sort of protection. The emergency dose would be reduced from 10,000 roentgens to 1000 roentgens. What have we accomplished in saving of lives? Essentially nothing, for 1000 roentgens is as lethal as 10,000 roentgens when delivered in so short a span of time. Places offering a factor of 10 reduction do not provide adequate shelter.

Let us next consider locations that provide a shielding factor of 100. The dose during the emergency phase would now be approximately 100 roentgens. This sort of protection is interesting, since we would expect no significant incidence of radiation sickness and, certainly, no deaths. In terms of living or dying, such shelter would be adequate. However, we must remind ourselves that we face an operational recovery dose of about 2000 roentgens when we emerge from shelter. We may be able to reduce this threat through the use of countermeasures, but a dose of 100 roentgens would be a considerable burden to take into the ensuing phase. Hence, a shielding factor of 100 may not represent adequate shelter under many conditions.

Suppose we could provide a shelter shielding factor of 1000. The emergency dose would then be only 10 roentgens. This is a very modest exposure, which could be neglected for practical purposes in dealing with the operational recovery phase. Thus, locations having a shielding factor of 1000 would certainly constitute adequate shelter.

There are apparently very few areas available in existing structures that offer a shielding factor of 1000. Therefore, special shelters would be required to provide this level of protection to the population. Since new construction is indicated, it is of interest to consider whether even better protection would be desirable. If we provided a shielding factor of 10,000 in special shelters, the emergency dose would be reduced to about 1 roentgen. But we have not really accomplished much because 1 roentgen is like 10 roentgens biologically, in the same sense that 1000 roentgens is like 10,000 roentgens at the other end of the scale. There is some small gain because there are limited areas of fallout in which the level is significantly greater than 3000 r/hr at 1 hr. Nevertheless, it appears that a shielding factor of 1000 constitutes adequate shelter and that additional protection would provide only marginal improvement.

We turn now to the operational recovery phase, in which a dose of 2000 roentgens may be expected. It is our opinion that reclamation or decontamination is the central countermeasure during this phase. Before considering the probable performance of reclamation, it may be useful to consider the alternatives that may be available. If our only requirement were safe living area for the population, one alternative would be to remain in shelter longer than two weeks; in fact, we might remain in shelter long enough to eliminate the requirement for countermeasures in the post-shelter

period. To achieve a factor of 10 reduction in post-shelter exposure (i.e., from 2000 roentgens to 200 roentgens) would require a shelter stay of about six months. It is clear that shelters designed for 6 months occupancy would be more costly than shelters designed for two weeks occupancy. Thus, reclamation might be preferable to providing for very long occupancy of shelters.

Another alternative would be to move the population after about two weeks to areas of the country that had not experienced significant levels of fallout; say, to areas outside the contours shown on the attack maps presented in previous testimony. These maps show that there are fairly large areas, mainly in the western half of the country, that would be available. Since these areas are sparsely inhabited regions of desert, mountains and plains, the task of providing minimal housing and other living accommodations for millions of survivors would appear to demand a major effort.

In any event, neither of the foregoing alternatives is very satisfying because we are interested in more than safe living areas for our population. We are interested in reviving the economic and political life of the country and in bringing the war to a successful conclusion. To do this, we must make safe for occupancy our surviving factories, plants, governmental facilities, and schools as well as living areas convenient to these facilities. Reclamation is the only practical means of accomplishing this task.

A large part of the research work on reclamation has been done by USNRDL. We believe that, with some training, a factor of 10 reduction in the post-shelter exposure could be expected using commonly-available equipment.

This would reduce the operational recovery dose to 200 roentgens. Since this dose would be spread over a period of a year, one would not expect casualties. If reclamation were used in conjunction with good fallout shelter, the framework for survival and recovery from radioactive fallout becomes evident.

If reclamation procedures are developed that achieve a factor of 100 reduction, the post-shelter dose could be reduced to about 20 roentgens. This is, of course, a nominal exposure. When combined with a shelter system that offers a factor of 1000 reduction during the emergency phase a very effective fallout defense would result in which the overall exposure to persons in the heavy fallout area would be of the order of 30 roentgens. It is also important to note that such an improvement in reclamation performance would ease the requirement for high-performance shelters, making use of locations offering a shielding factor of 100. Reclamation reduction factors of 100 have been achieved experimentally but there is some doubt that such performance could be achieved in practice. In this respect, it can be seen that it may be important to encourage further experimentation in the field of reclamation on the basis that it will ease the requirement for construction of shelters.

Figure 1 also shows that efforts to provide a reduction factor in operational recovery greater than 100 is not likely to have a significant bearing on the overall radiological defense system.

The possible systems of countermeasures that result in exposures that may be acceptable are shown in Figure 2. Performance is given in terms of residual number, which is the inverse of reduction factor. It can be seen that a reclamation residual number of 0.1 (factor of 10 reduction)

SURVIVAL ARITHMETIC

Heavy Fallout Area: 3000 r/hr at 1 hour

Dose during first year	12,000 Roentgens
Dose during first 2 weeks	10,000 "
Dose between 2 weeks and 1 year	2,000 "

EMERGENCY PHASE

10,000 Roentgens

OPERATIONAL RECOVERY PHASE

2,000 Roentgens

Shelter Shielding Factor	Emergency Dose	Reduction Factor	Operational Recovery Dose
10	1000 Roentgens	10	200 Roentgens
100	100 "	100	20 "
1000	10 "	1000	2 "
10,000	1 "		

Figure 1

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Useful Radiological Defense Systems

Heavy Fallout Area: 3000 r/hr at 1 hr

System Number	Emergency Phase Countermeasures	Operational Recovery Phase Countermeasures	Dose during First Year (roentgens)
1.	6-month shelter with 0.01 residual number	None	320
2.	6-month shelter with 0.001 residual number	None	210
3.	2-week shelter with 0.01 residual number	0.1 reclamation	300
4.	2-week shelter with 0.001 residual number	0.1 reclamation	210
5.	2-week shelter with 0.01 residual number	0.01 reclamation	120
6.	2-week shelter with 0.001 residual number	0.01 reclamation	30

Figure 2

reduces shelter stay from 6 months to 2 weeks and that improved reclamation (residual number of 0.01) is needed to bring the total dose to less than 200 roentgens, even with good shelters. It is difficult to estimate the cost of these systems at the present time. The principle unknowns are the total shelter space available in existing structures that offer adequate protection and the potential cost, if any, of the higher-performance reclamation procedures. However, it is probable that system number 2 is the most costly and that system number 3 is the least costly.

The foregoing discussion has considered conditions in the heavy fallout area (3000 r/hr at 1 hr) despite the fact that only about 20% of the population would be involved so seriously in the attack under consideration. The main justification for this approach is that one cannot predict in advance which areas are going to be subjected to high levels of fallout. Unless one is prepared to sacrifice such areas, wherever they may occur, all persons who may be potentially subject to heavy fallout must be given adequate protection. This means virtually everyone.

At the same time, it must be remembered that most of the fallout area will be subjected to a lesser threat. Consequently, less effective systems can still save many lives. For example, consider the threat in a region sustaining a fallout level equivalent to 300 r/hr at 1 hr. All the doses in Figure 1 would be reduced by a factor of 10. The dose in the emergency phase would be approximately 1000 roentgens and the dose during the remainder of the year would be but 200 roentgens. A shielding factor of 10 (home basements) would hold the emergency dose to 100 roentgens. Shelters offering a shielding factor of 100 would keep the emergency dose at a nominal level. If no reclamation were attempted, no casualties would be expected (200-300

roentgens over a period of one year), although longer-term effects might become apparent in the population. Reclamation would confine exposures to a nominal level.

At somewhat lower levels (less than 100 r/hr at 1 hr), the need for a formal radiological defense system disappears, it being sufficient to remain indoors or in available shelter for the first day or two after attack.

It has been noted that the shielding afforded by existing buildings may offer effective protection in light and moderate fallout areas. The number of shelter spaces that might be available in locations offering a shielding factor of, say, 100 is not known because routine techniques for making such assays have only recently become available.[1,2,3] It is almost certainly true that most buildings that offer good fallout protection are located in target areas in which effects of blast and fire are also likely. Estimates of the fraction of the population that can be afforded various levels of fallout protection are somewhat arbitrary at this time.

Even where good fallout protection can be identified in existing structures, it cannot be assumed that this protection is available without cost. Such areas must be occupied for several days to weeks. Although it may be possible for people to survive without food and water or sanitary facilities for some period, in general, these items must be provided. It is also generally true that such spaces are not adequately ventilated for shelter use. Unless one restricts the number of shelter occupants to those that could be maintained in a habitable environment using existing ventilation,— an unlikely restriction considering the limited availability of such space— additional ventilation facilities would be required. Rand

Corporation estimated[4] that it would cost \$25 - \$35 per person sheltered to convert a mine into a usable personnel shelter. My own experience in shelter design leads me to the conclusion that a similar amount would be required to produce usable fallout shelters in existing structures.

The fact that there is probably insufficient good fallout shelter in existing structures to house the population together with the fact that better protection than existing structures provide may be necessary has placed emphasis on the problem of building shelters specifically for the purpose. Concern with the design of fallout shelters is of fairly recent origin. Virtually all tests of shelters at nuclear weapons tests have been concerned with blast protection, it being tacitly assumed that a satisfactory blast shelter would be completely satisfactory for fallout protection. Yet little attention was paid to the effect of entrance and ventilation openings on shielding, the requirements for ventilation during fallout, and the requirements for habitability under extended occupancy conditions. At Operation PLUMBBOB in 1957, USNRDL was afforded the opportunity to participate in the Civil Effects Test Group program in this field. I was project officer on a project sponsored by the AEC that investigated some of these matters by occupying an experimental shelter at a close-in location relative to several nominal-yield nuclear detonations. The shelter we used was a buried ammunition storage magazine that had been shown in previous tests to offer very good blast protection at a comparatively low cost. I have with me a short documentary film on this project that can be shown to the committee at its pleasure. The project was fairly successful at accomplishing its objectives.[5] Information was obtained that formed a basis for design of suitable entrances, ventilation systems

and other features.

Following this operation, a design study was undertaken that attempted to design a satisfactory fallout shelter at minimum cost.[6] In this study, now completed, we propose a set of minimum performance specifications for protection, access time, habitability and the like. We then designed in detail a shelter meeting these specifications, based on the ammunition storage magazine previously tested. Figure 3 is an artist's sketch of the result. Within the basic specifications we considered a number of alternatives with respect to the degree of austerity in living accommodations, comfort in the shelter environment and the like. We then attempted a detailed cost estimate. This procedure gave us not only an estimate of total shelter costs but also some understanding of the cost of making people comfortable, of providing filtered air, of providing increased blast protection, and of providing various levels of creature comfort in living accommodations. The results indicate that we should be able to provide adequate fallout shelters of this type (shielding factor of at least 1000) for approximately $100 - $125 per person sheltered. These shelters would also provide protection against blast overpressures up to 10 psi. It is anticipated that buried shelters of this type could be located in groups under school playgrounds, parks, storage and parking areas in industrial plants and similar areas.

This study also points out that insufficient information exists on a number of subjects essential to the efficient design of shelters. Based on a review of the preliminary draft of the report on the study, the Office of Civil and Defense Mobilization has requested that the Laboratory construct a prototype shelter and conduct the necessary experiments to

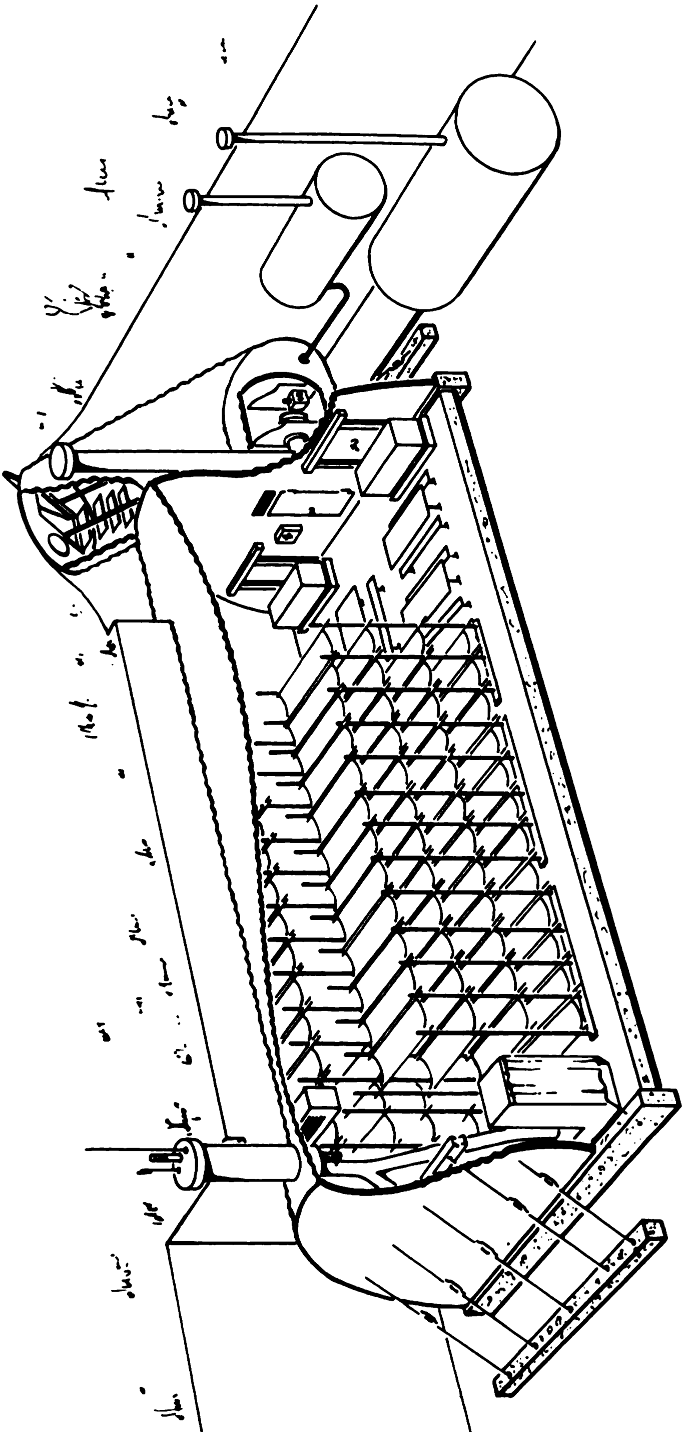

Figure 3

resolve these questions. A prototype shelter is under construction at Parks AFB near Livermore, California. Some additional insight into the problem of shelter costs will be gained by building this shelter. Experiments will begin in August of this year. The shelter tests will include studies of the environment inside the shelter using heat and moisture sources to simulate the shelter occupants, of the shielding provided by the newly-designed entrance, of the ingress of fallout particles into the shelter through the ventilation system and the like. Design changes will be made based on these studies. Ultimately, it is hoped to prooftest the shelter by occupying it for a two-week period. The end result will be the first fully-tested design of a high-performance fallout shelter available in this country.

Turning now to the post-shelter problem of recovering the use of essential facilities needed to reconstruct the economy, I would like to expand briefly on my previous statement that reclamation using commonly-available equipment can be expected to achieve at least a factor of 10 reduction in the post-shelter exposure. This statement is based on a considerable history of experimentation beginning at Operation JANGLE in 1952. More recently, field experiments have been conducted at Camp Stoneman in California using simulated land fallout. Work of this type will continue under OCDM sponsorship at Parks AFB. Areas of this base, which is being turned over to the Army shortly, have been set aside for USNRDL research work. The principal weakness in present knowledge stems from the fact that no experimental reclamation of actual facilities such as industrial plants, oil refineries and residential areas has been accomplished, previous studies being confined to typical elements such as

streets, roofs, etc. Experimental decontamination of complex target facilities are planned for the near future. The results should indicate to what extent the effectiveness seen on typical elements (reduction factor of 100) can be expected in real situations. The work should also result in well-designed procedures that can be used to train recovery crews on a country-wide basis. Meanwhile, USNRDL is estimating for OCDM, based on present knowledge, the effectiveness and cost of reclaiming specific facilities considered essential for post-attack recuperation of the economy.

One can gain some understanding of the effect of various levels of fallout protection upon human casualties by calculating the performance of possible radiological defense systems under the fallout conditions laid down in the hypothetical attack selected for these hearings. One difficulty hinges on the definition of the term, "casualty." One interpretation might be whether a person lives through the attack or dies. On the other hand, some criterion of injury might be selected that would consider either radiation sickness or longer term effects, perhaps even genetic effects. The importance or non-importance of these effects has been discussed in prior testimony.

I shall avoid an arbitrary definition of a radiation casualty by presenting calculations showing the fraction of the total population receiving various radiation doses that might be used to define the term. In making these calculations, I consulted Dr. Joseph Coker of the National Damage Assessment Center to obtain an estimate of the fraction of the population located in areas that received various levels of fallout. Using this information, I obtained the results shown in Figure 4. I have

PERCENTAGE OF TOTAL POPULATION RECEIVING RADIATION
EXPOSURES IN HYPOTHETICAL ATTACK

Defense System	Dose in First 2 Weeks					Dose in First Year				
	< 50r	< 150r	< 300r	< 600r	> 600r	< 50r	< 150r	< 300r	< 600r	> 600r
Unprotected	11	18	26	34	66	10	15	22	31	69
0.1 shelter, no reclamation	23	42	58	77	23	16	26	35	47	53
0.1 shelter, 0.1 reclamation	23	42	58	77	23	26	38	51	69	31
0.01 shelter, no reclamation	71	92	99	100	0	18	30	40	50	50
0.01 shelter, 0.1 reclamation	71	92	99	100	0	40	63	88	98	2
0.01 shelter, 0.01 reclamation	71	92	99	100	0	65	90	98	100	0
0.001 shelter, 0.1 reclamation	100	100	100	100	0	45	73	92	99	1
0.001 shelter, 0.01 reclamation	100	100	100	100	0	92	100	100	100	0

Figure 4

considered two exposure periods, 2 weeks and 1 year. The first period is associated with the emergency phase and shelter performance; the second with both shelter and reclamation. The first is a period of acute exposure where the question of living or dying is decided in the main. The longer period is mainly of concern in terms of the health and vitality of the population and of future generations. In the body of the table are the percentages of the total population that will receive, for a number of assumed defense systems, less than 50, 150, 300, and 600 roentgens as well as the percentage that will receive over 600 roentgens.

Some generalizations might be made from this table. A completely unprotected populace would be very vulnerable to fallout from this attack. Perhaps 70% would die. If all persons were provided with shelter having a residual number of 0.1 (factor of 10 reduction), only 25 to 30 percent would die. A shielding factor of 100 would assure virtually no deaths from fallout radiation. However, if no reclamation were attempted in the post-shelter phase, large numbers of people would receive massive doses during the ensuing year. The last four systems in the table appear to be quite satisfactory, with the choice depending upon the attention that must be paid to the long-term effects of radiation.

The higher-performance radiological defense systems shown in Figure 4 are such as to assure that few, if any, radiation deaths will result from the hypothetical attack. Deaths from blast and fires have not been considered. In this respect, it should be recalled that the buried fallout shelter described earlier was capable of withstanding 10 psi blast overpressure. Mass fire protection has also been provided. If such shelters were provided as part of the last two systems of Figure 4, total

casualties from all effects would be limited to about 8 percent of the population. This may be compared with the blast and fire casualty estimates of previous witnesses. The same shelter can also be designed to resist 35 psi at an increase of perhaps 50 percent in cost per person sheltered. If such shelters were provided, total casualties would be reduced to about 3 percent of the population. Deep underground shelters would be required in target areas to further improve the situation. One caveat should be placed on the foregoing. It is assumed that sufficient warning of attack occurs that people are in shelter at time of burst. Warning requirements are not as stringent for fallout protection, since a considerable period of time elapses between detonation and arrival of fallout.

The main conclusion one can reach from study of Figure 4 is that some sort of radiological defense system is absolutely necessary. That is, if we are to survive the sort of attack hypothesized, we must have shelters for our population and we must be capable of reclaiming our essential surviving resources. It may be useful to consider the possible costs that would be involved.

Suppose, on the one hand, it is decided not to build new shelters, but rather to shelter the population in existing buildings, tunnels, mines and the like, carefully selecting the locations so that maximum possible protection is afforded. Assuming that we need approximately 200 million shelter spaces and that it will cost about $25 per shelter space to provide minimum ventilation, outfitting and supplies, such a course of action would entail the expenditure of approximately 5 billions of dollars. If, on the other hand, it is decided to build a system of fallout shelters, perhaps of the type shown in Figure 3, it would cost about 20 billions of

dollars.

Another course of action that has considerable merit would be to exploit only the best protected areas of existing structures (better than a factor of 100), supplementing these with the necessary new construction to house the total population. The cost of such action would lie between 5 and 20 billions of dollars, depending on the portion of the population that could be sheltered in existing structures.

The dollar cost of reclamation will be very small, since the principal problems are ones of organization and training. (There are post-attack costs of manpower, materials and radiation dose that will constitute a demand on surviving resources.) For purposes of assessing the costs of preparing a defense, costs of reclamation may be neglected.

In summary, the principal costs of the radiological defense measures that appear essential to national survival will be those attributable to the provision of adequate shelter, and these costs may be expected to lie in the range of 5 to 20 billions of dollars.

References

1. "Radiological Recovery of Fixed Military Installations," TM-3-225 or NAVDOCKS TP-PL-13, Departments of the Army and the Navy (April 1958.

2. "A Method for Evaluating the Protection Afforded by Buildings Against Fallout Radiation" Office of Defense Mobilization, Washington 25, D.C. (Sept. 1957).

3. "Guide for Fallout Shelter Surveys, Interim Edition," Office of Civil and Defense Mobilization, Battle Creek, Michigan (Feb 1959).

4. RAND Report R-322-RC, "Report on a Study of Non-military Defense" (July 1958).

5. WT-1464, Operation PLUMBBOB, Project 32.3, "Evaluation of Countermeasures System Components and Operational Procedures".

6. W.E. Strope, et al, "A Study of the Specifications and Costs of a Standardized Series of Fallout Shelters" USNRDL Technical Report in preparation.

Representative HOLIFIELD. Thank you very much, Mr. Strope.

Mr. STROPE. Thank you, Mr. Chairman.

Representative HOLIFIELD. Before we recess for lunch, I have a paper that we requested from Robert Corsbie of the AEC which I would like to place in the record at this point.

Technical Consideration On Survival Measures and Reduction of Casualties

By: R. L. Corsbie, U. S. Atomic Energy Commission

PART A

Introduction and Background

The Atomic Energy Commission has on many occasions presented testimony to the Congress on AEC programs related to laboratory and field research concerning the effects of nuclear detonations on man and his environment and the utilization and dissemination of the information. Some of the presentations are reported in:

1. Hearing before the Subcommittee on Security of the Joint Committee on Atomic Energy, Congress of the United States, 84th Congress, 1st session, on AEC-FCDA Relationship - 1955;

2. Hearing before the Joint Committee on Atomic Energy, Congress of the United States, 84th Congress, 1st session, on Health and Safety Problems and Weather Effects Associated with Atomic Explosions - 1955;

3. Hearings before the Subcommittee on Civil Defense of the Committee on Armed Services, U. S. Senate, 84th Congress, 1st. session, on Operations and Policies of the Civil Defense Program-1955;

4. Hearing before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, Congress of the United States, 85th Congress, 1st session, on the Nature of Radioactive Fallout and its Effects on Man - 1957;

5. Hearing before the Subcommittee of the Committee on Government Operations, House of Representatives, 85th Congress, 2nd session, on Atomic Shelter Tests - 1958.

This statement is intended to:

1. include evaluations, conclusions and new data reached or developed in the Civil Effects Test Group subsequent to the 1957 Hearings on the Nature of Radioactive Fallout and its Effects on Man and the 1958 Hearing on Atomic Shelter Tests;

2. describe and summarize the special exercises and projects, initiated in 1955 in correlation with and in extension of weapons tests, which are continuing as part of the overall AEC program in studies on the effects of nuclear detonations, and

3. summarize the current and projected nuclear energy civil effects program which is part of the USAEC, Division of Biology and Medicine overall program.

Background

The AEC believes that its most effective contribution to national self-protection will be made by furnishing technical assistance and information essential to non-military defense plans and operations. It has conducted jointly with the Department of Defense a program through which classified and unclassified technical reports on nuclear effects numbering in the hundreds have been made available to other Federal agencies, and to the public. Arrangements have been made through which Federal, state and local technical personnel have conducted tests and training exercises at the AEC Nevada Test Site in the course of weapons test series and at other times to obtain required information. In support of the non-military defense public information program, "open shots" have been scheduled so that hundreds of Federal, state and local officials and other non-military defense participants have had the opportunity to witness and to report on nuclear detonations and to observe first-hand their close-in effects.

Wherever access to plants and facilities are controlled because of safety and security considerations, the AEC through long-standing policy and interagency agreements has assumed responsibility for self-protection at such plants and sites. Among the Federal agencies this self-protection task is believed to be second in magnitude only to that of the Department of Defense. In accepting this important self-defense responsibility the AEC has found it necessary to develop and support a nuclear effects program to provide input data for its own use while at the same time actively seeking to avoid a position which might identify it in the mind of the public as the Federal agency having primary responsibility for National non-military defense planning.

In implementation of this policy there was initiated in 1951 a continuing program of investigation and study to understand the effects phenomena associated with nuclear energy. The results provide the base for criteria and recommendations to protect AEC personnel, those of our contractors and the general public from any harmful effects of nuclear reactions whether resulting from accidents in the laboratory, nuclear materials in transit, the reactors serving peacetime applications, the nuclear detonations in weapons tests and nuclear explosions in non-military uses, or the results of nuclear attack through enemy action.

The need for civil effects data has from the date of the first nuclear reaction paralleled and kept pace with advances in weaponry and other applications of nuclear energy but our knowledge of the effects given by a family of nuclear weapons of a variety of designs, geometries, materials and yields has lagged behind the development of the weapons and because of this there are gaps in knowledge on the prevention and treatment of injuries caused by nuclear effects and on effective countermeasures against physical damage.

Federal leadership is recognized as being of prime importance in the U. S. non-military defense effort which is expected to include the participation of all members of the Federal Family. The AEC is generally recognized as an agency well fitted to further this program for the benefit of itself, the communities in which its facilities are situated, and the National deterrent capability.

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CIVIL EFFECTS TEST OPERATIONS - CIVIL EFFECTS TEST GROUP PARTICIPATION OPERATIONS PLUMBBOB AND HARDTACK, PHASE II

PART B

The program of civil effects for Operations PLUMBBOB, 1957, and HARDTACK, Phase II, 1958, originated primarily in the Atomic Energy Commission, the Federal Civil Defense Administration (later Office of Civil and Defense Mobilization) and the Department of Defense. Project participation also included other government agencies, private industrial groups and West Germany and France.

The scientific and technical programs comprised many kinds of studies and investigations relating to continuing efforts to improve the probability of survival and continuity of production in wartime and to safeguard health in peacetime applications of atomic energy.

Insofar as is consistent with the National security, results of these tests are made available in unclassified reports. The ITRs and WTs of the various projects contain the results from this series of studies.

Operation PLUMBBOB 1957

During Operation PLUMBBOB the Civil Effects Test program contained over fifty field projects designed to increase our knowledge of weapons effects and countermeasures. Continuing the practice followed in earlier series the program represented a combination of many interests of AEC, DOD, FCDA and industry.

There were ten major programs. Program 30, Shelters for Civil Population and Program 31, Structures, Equipment, Devices and Components, were sponsored and conducted by the Federal Civil Defense Administration and its contractors. A major portion of Program 30 consisted of the test of shelters on behalf of the French and West German governments.

Program 35, Radiological Defense Technologies, and Program 36, Radiological Defense Operations, were also Federal Civil Defense Administration programs conducted in support of the civil defense radiological defense effort.

The AEC sponsored study of radiological countermeasures was concentrated in Program 32.

PROJECT 32.1: Attenuation Factors-Shielding and Decontamination - HASL

The purpose of this Project was to confirm by field exercise the calculations by which the dose rate within a simple structure may be related to the free-field intensity and the effectiveness of decontamination procedures. Manuscript not received from author.

PROJECT 32.2: Field Use and Development of Aerial Radiological Monitoring System - HASL

In this Project flights were made over contaminated areas following two detonations to test the calibration and utility of an aerial survey system designed for civil defense applications. The field experience was utilized in further developmental work. The manuscript not received from author.

PROJECT 32.3: Systems Operations Exercise and Evaluation - NRDL

In this Project measurements were made inside a manned shelter beginning at shot time to (1) test a simple shelter monitoring system; (2) test a proposed ventilation system; (3) determine the shielding afforded by the shelter; (4) determine the radiation and fallout characteristics needed to evaluate the operational measurements.

Data were obtained on two shots. The shelter, having a minimum earth cover of 3 feet, provided an average shielding reduction factor of about 10,000. From a radiological viewpoint the entryway was not as effective in shielding against radiation as the shelter proper and needs redesign. The shelter monitoring system provided adequate information. Because of accidental blast damage to a generator room outside the shelter, a satisfactory test of the ventilation system was not achieved. Experience was gained in post-attack radiological recovery operations. Reported in ITR-1464 - unclassified. WT draft being processed for printing.

PROJECT 32.4: Fallout Studies and Assessment of Radiological Phenomena - NRDL

This Project was conducted to develop information important to research on radiological recovery and to furnish support to Project 32.3. Comparison was made of the ionization from an infinite plane photon source to that of a real surface having attenuating irregularities, i. e., the Nevada desert soil. The attenuation was found to be a function of time since detonation and to fall off rapidly with height, becoming small at about 50 feet above the terrain.

Comparisons were made on fallout particles resulting from similar devices fired on a tower and a balloon to evaluate the effect of towers on the nature of the fallout particles. Reported in ITR-1465 - unclassified - WT draft being processed for printing.

In Program 33 investigations of the biological effects of blast and environmental hazards were continued.

PROJECT 33.1: Primary and Tertiary Blast Effects - Lovelace Foundation

Dogs, pigs, rabbits, guinea pigs, and mice were exposed to nuclear detonations in two open-door underground partitioned shelters of similar construction to determine the effects of overpressure and the

translational effects of the dynamic pressure. One dog was severely injured by translational effect at a dynamic pressure of 10.5 psi; another was uninjured at a dynamic pressure of 2 psi.

Primary blast effects, i. e., the effects of the overpressure were minimal in the range of 4.1 psi to 30.3 psi. Reported in ITR-1467 - Official Use Only - WT draft being processed for printing.

PROJECT 33.2: Missiles Secondary to Nuclear Blast - Lovelace Foundation

Secondary missiles were studied in open regions where peak over-pressures ranged from 4 to 23 psi. Missiles studied originated from window glass mounted in frames, marked military debris, marked gravel, marked spheres, and native stones. Displacement distance was measured for stones weighing up to 42 lbs. at various ranges from ground zero. Velocities for spherical missiles were measured in a shelter with open entryway where the peak overpressure was 65 psi. Glass fragment missiles from windows were studied in two houses. Reported in ITR-1468 - Confidential

PROJECT 33.3: Tertiary Effects of Blast - Displacement - Lovelace Fdtn.

The objective was to determine the velocity and distance of translation of anthropomorphic dummies and equivalent spheres caused by blast winds for correlation with laboratory work with biological material. Reported in ITR-1469 - Unclassified - WT draft being processed for printing.

PROJECT 33.4: Missile Studies with a Biological Target - Lovelace Fdtn.

Animals were used in two shots to study the injury-producing capabilities of secondary missiles generated in houses and in the open exposed to glass and gravel missiles generated by pressures ranging from 8.4 psi to 3.7 psi. Reported in ITR-1470 - Official Use Only

PROJECT 33.5: The Internal Environment of Underground Structures Subjected to Nuclear Blast. 1. The Occurence of Dust - Lovelace Fdtn.

The possible occurence of dust inside protective shelters as a consequence of nuclear explosions was studied using 18 underground structures subjected to atomic detonations at distances ranging from 4320 to 840 feet from ground zero. The existence of considerable dust was established. Reported in ITR-1447 - Unclassified

PROJECT 33.6: The Internal Environment of Shelters Subjected To Blast II. Effects on Mice Located in Heavy Concrete Shelters - Lovelace Fdtn.

Mice were used to assess biologically the inside environment of two designs of heavy concrete personnel structures. A sample consisted of 20 mice; one sample was used in each of 12 structures. Aside from two samples placed in unrealistic locations, there was no immediate mortality. Reported in ITR-1507 - Unclassified

PROGRAM 34 - Physical Response to Blast Loadings -

In Program 34 the investigations were directed to the physical response of structures and components under blast loadings.

PROJECT 34.1: Effects of a Non-Ideal Shock Wave on Blast Loading of a Structure - Sandia

Studies were made of the effects on three-dimensional structures by blast at 20-25 psi and 90 psi. Reported in ITR-1472 - Confidential

PROJECT 34.2: Comparison Test of Re-inforcing Steels - Sandia

The purpose of this Project was to compare the responses of rail and intermediate grade steel when used as re-inforcing in concrete beams subjected to blast loading in the range of 7 psi and 5 psi. The rail steel slabs exhibited a permanent deflection at least 50% less than the intermediate grade steel slabs. Reported in ITR-1473 - Official Use Only

PROJECT 34.3: Test of Buried Structural-Plate Pipes Subjected to Blast Loading - Holmes and Narver

Two 20-foot-long, 7-foot-diameter, 10-guage corrugated, structural-plate pipes having longitudinal joints with 8 bolts per foot were buried and tested at measured pressures of approximately 170 and 195 psi. Depth of burial was 10 feet.

Maximum transient changes in vertical and horizontal diameters measured by self-recording guages were about 7/8 inch and 3/8 inch respectively. Maximum residual changes in the same diameters were about 3/4 inch and 1/4 inch. Slip in bolted joints were negligible. Reported in ITR-1474 - Unclassified

PROJECT 34.3a: Evaluation of Nuclear Effects on AEC Test Structures-Holmes and Narver

Measurements were made of various components of the test structures to develop information of value in structural design of test facilities. Manuscript not received from author.

PROJECT 34.4: Systems Test of AEC Absolute Filters - Harvard/Sandia

The objectives of this Project were to determine the effects of blast on air filtration devices and typical gas-cleaning systems in the 3- and 1- psi overpressure range and to determine certain characteristics of the system as affected by blast. Test results showed no damage to AEC filters and only minor damage to fiberglass filters. Field tests appear to agree with laboratory studies and indicate that future tests can be conducted in laboratory shock tubes. Reported in ITR-1475 - Unclassified

PROGRAM 37 - Radio-Ecological Aspects of Nuclear Fallout - UCLA/USGS

This Program consisted of seven Projects conducted to further the knowledge of fallout. In effect the work was a continuation of studies initiated in 1947 at the site of the July 16, 1945 detonation at Alamagordo, New Mexico.

Projects were:

37.1 Biological Accumulation of Fission Products Fallout

37.2 Biophysical Aspects of Fallout Phenomenology

37.2a Identification and Documentation - Physical Aspects of Fallout

37-3 Fallout Materials on Agricultural Environments

37-4 Measurement of Fast Neutron Doses by Germanium Dosimeters

37-5 Measurements of Ionizing Radiation by Chemical Methods

37-6 Applications of Radio-ecological Techniques

The main purposes of these studies were (a) learning to control the availability of radioactive fallout to plants, animals, and man; (b) defining accurately the limits of environmental radiation that can be safely tolerated.

The studies can be divided into two parts: (1) the acute or immediate hazards arising primarily from external radiation and (2) the chronic or long-term hazards arising primarily from internal emitters.

To meet these requirements, the field work involved:

(1) delineation of fallout patterns and characterization of the fallout material at the time of deposition

(2) analysis of fallout materials to determine the changes in characteristics with time

(3) collection of data on biological fate and persistence of fallout debris during the period following contamination

(4) documentation of contamination on agricultural areas.

Associated with the fallout studies were projects to study the prompt radiation at time of detonation and a project to train professionals in methods of fallout assessment. Reported in ITR-1492 - Confidential Manuscript for proposed ITR-1488 not received from author. Fallout maps (12) and survey methods and calculations issued 1957-58.

PROGRAM 38 - Effects of Radioactive Fallout on Foodstuffs - FDA/UCLA

This Program was conducted at the Nevada Test Site up to June 30, 1957 by the Food and Drug Administration in the interests of civil defense. The program was coordinated with Program 37 and was continued in the field from July 1, 1957 to completion by Program 37 personnel. WT-1461 - Unclassified - has been printed and distributed. Manuscripts of proposed WT-1496 and 1497 being processed for printing. Manuscript of proposed WT-1498 not received from author.

PROGRAM 39 included Projects established to furnish instrumentation and data needed by CETG, such as neutron and gamma dosimetry and pressure and thermal measurements. The results are included in the following reports:

Proj. 39.1 Neutron and Gamma Measurements Utilizing the USAF Chemical Dosimeters - SAM/DBM - reported in ITR-1500- Confidential

Proj. 39.1a Gamma Dosimetry by Film-Badge Technique - EG&G - reported in WT-1466 - Secret - in process

Proj. 39.1b Neutron Dosimetry by the Threshold Detector Technique - ORNL/EG&G - reported in WT-1471 - Secret - in process

Proj. 39.2 Static and Dynamic Pressure Measurements - BRL/ARF/SC reported in ITR-1501 - Confidential - in process

Proj. 39.3 Thermal Radiation Measurements - NRDL/U of Rochester - reported in ITR-1502 - Confidential.

Program 39 also included the following group of significant projects to investigate the biological effects of radiation.

PROJECT 39.5: Radiation Dosimetry for Human Exposure - ORNL/SAM/LASL

This Project collected data on the angular distribution of prompt neutron and gamma radiation from bomb detonations. Data on the attenuation of these radiations by light wood houses were also obtained to evaluate the shielding afforded individuals in such structures and for correlation with ABCC data and records. Reported in WT-1504 - Secret

PROJECT 39.6: Radiation Studies and Human Evaluation - SAM/ORNL/LASL

Experimental animals (monkeys) were exposed to ten different radiation doses ranging from a few rep to about 1,000 rep of mixed bomb neutron and gamma radiations. The animals were examined immediately after the shot for signs and symptoms of radiation injury and have been continually followed for long-term effects. The data from these studies are being correlated with physical measurements of Project 39.5 in studies on other animals from both laboratory and field experiments to provide a better understanding of human response to radiations from nuclear weapons. Reported in WT-1505 - Secret

PROJECT 39.6a: Correlation of Effects of Bomb and Laboratory Radiation on Burros - UT/AEC

Experimental animals (burros) were exposed to ten different radiation doses ranging from a few rep to about 1,000 rep. The animals were examined immediately after the shot for signs and symptoms of radiation injury, held at the test site for a 40-day period and survivors returned to the laboratory where they have been continually followed for long-term effects. These data are being correlated with other biological

and physical data and have provided information on effect of body size on animal response to radiation which will contribute to a better understanding of the means for extrapolation from animal to human response. Reported in ITR-1476 - Official Use Only

PROJECT 39.7: 39.7a: Delayed Effects of Bomb Radiation on Small and Large Animals - LASL/SAM/BRL/NMRI/ORNL/OSG

In these Projects biological materials and dosimeters were used to provide data for correlating exposures with effects and extrapolating the findings to probable medical effects on human beings. Several species of animals such as mice, guinea pigs, rabbits, monkeys, dogs, swine, and burros - animals routinely used for biomedical research - were exposed. Differences exist in response to radiation exposure between different animal species, and a fundamental purpose of these projects was the collection of data from full scale detonations when accurate physical measurements were being made. The data thus obtained may make more meaningful a wealth of earlier laboratory and field experience. Manuscript not received from author.

PROJECT 39.8: Depth Dose Studies with Initial Bomb Gamma and Neutron Radiation - NMRI/BNL

In this Project measurements of the depth dose of initial bomb gamma and neutron radiations were made using tissue equivalent phantoms. These data will aid in determining the effective exposure geometry of the initial radiation and will be correlated with the other physical and biological measurements. WT-1508 being processed for printing - Secret

PROJECT 39.9: Remote Radiological Monitoring - AEC

In this Project the feasibility of a remote monitoring system on-site and off-site was established. Off-site the system employed radiation detectors at 30 locations around the test site in California, Nevada and Utah. Communication with the detectors was accomplished via commercial telephone lines, the telemetered data being read out by equipment at the test site on command. On-site the detectors were placed in locations where early information of radiation environment was needed in order to minimize exposures to human monitors. They were linked to a central readout system by land lines. The data and experience gained from this Project demonstrates the feasibility of utilizing telemetering techniques on-site as a means of obtaining radiological survey data. WT-1509 being processed for printing.

PROJECT 39.9a: Botanical Study of Nuclear Effects - Highlands Univ.

This is a continuing ecological project conducted to gain data on the effects of nuclear detonations on plant life at the Nevada Test Site. ITR-1534 being processed for printing.

Operation HARDTACK, Phase II 1958

Operation HARDTACK, Phase II, was conducted during September and October of 1958 and the effects experiment were essentially extensions of Operation PLUMBBOB 1957. The Civil Effects Test Operation provided for the administration and technical coordination of the effects program for the Civil Effects Test Group and the Office of Civil and Defense Mobilization. The projects were as follows:

Civil Effects Test Group Projects:

Project 34.1 Physical Damage Survey - H&N
Project 34.2 Radiation Instrumentation - H&N/EG&G
Project 34.3 Blast Instrumentation - H&N/BRL
Project 37.1 Further Evaluation of Balloon Shot Fallout Patterns - UCLA/USGS
Project 39.1 Prompt Radiation Dose Distribution in Light Frame Houses - ORNL
Project 39.2 Angular Distribution and Penetration of Prompt Radiation - ORNL
Project 39.9a Botanical Study of Nuclear Effects at the Nevada Test Site - Highlands Univ., N. M.

Office of Civil and Defense Mobilization Test Group Projects:

Project 70.1 Field Test Aerial Survey Instrument - V-780 - OCDM
Project 70.2 Radiation Attenuation in Soil - OCDM/EG&G
Project 70.3 Retest and Evaluation of Antiblast Valves - OCDM
Project 70.4 Effect of Nuclear Weapons on OCDM Family Fallout Shelter - OCDM
Project 70.5 OCDM Support Blast Measurements - BRL
Project 70.6 Air Blast Phenomena in Tunnels - BRL

The Civil Effects Test Group Projects originated in the AEC and are reported here. The OCDM Test Group Projects were included at the request of OCDM and it is assumed will be reported by that agency.

PROGRAM 34, Nuclear Effects, AEC Test Structures contained projects 34.1, Physical Damage Survey, 34.2, Radiation Instrumentation and 34.3, Blast Instrumentation. The objectives of the program were to utilize existing structures and instrumentation to obtain response data by recording and measuring their behavior under test conditions. These data are of importance for the engineering design of test structures, shelters and other supporting facilities. Many of these structures were very close to the detonations, thus providing a unique opportunity to make measurements and to obtain data on severe close-in effects. Manuscripts of ITR-1701 and 1723 not received from author.

PROGRAM 37, Further Evaluation of Balloon Shot Fallout Patterns, measured levels of fallout contamination by the use of aerial survey techniques and correlated these with ground measurements. The fate of the fallout will be followed by re-surveying certain previously established biological collection areas where soil samples have been periodically collected and analysed and where uptake of radioactivity by plants and native animals is followed. Manuscript of WT-1724 not received from author.

PROGRAM 39, Radiation Dosimetry for Human Exposures, consisted of projects 39.1, Prompt Radiation Dose Distribution in Light Frame House, 39.2, Angular Distribution and Penetration of Prompt Radiation and 39.9a, Botanical Studies of Nuclear Effects at the Nevada Test Site. Projects 39.1 and 39.2 were continuations of work done in Operation PLUMBBOB 1957 which was designed to provide data on (1) total air dose of prompt neutron and gamma radiation; (2) angular distribution of the prompt neutron and gamma radiation; (3) radiation dose distribution inside light frame houses and (4) data on shielding by slabs of building materials. These data are being correlated with field information from the Atomic Bomb Casualty Commission to improve knowledge of bomb radiations on human populations.

Project 39.9a is a continuing botanical and ecological study of vegetation within the Nevada Test Site and its environs.

The moratorium on nuclear tests has introduced many problems in fulfilling the need for effects data and made urgent and imperative a careful re-examination of available data and search for alternate means of obtaining the information necessary to live with the by-products of nuclear reactions.

CIVIL EFFECTS TEST OPERATIONS - SPECIAL PROJECTS AND EXERCISES

PART C

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Through the Division of Biology and Medicine and the Civil Effects Test Operations Office, the AEC conducts certain technical tests, exercises, surveys, and research directed principally towards practical applications of nuclear effects information and to encourage better technical, professional and public understanding and utilization of the vast body of facts useful in the design of countermeasures against weapons effects. The activities do not require nuclear detonations. Some are conducted at the Nevada Test Site and are designed to utilize the facilities remaining from weapons tests, using simulants and substitutes for nuclear reactions in continuing studies.

The information gained is of value not only to the AEC but also in disaster programs of other Federal agencies, States and cities, and to universities, laboratories, scientific, professional and technical groups and individuals interested in practical planning for protect'on against fallout radiation and other effects. The following list summarizes these activities to date:

Operation ARMS (1955): Aerial Radiological Monitoring Exercise - HASL/DBM

The operation consisted of an aerial radiological monitoring exercise conducted at NTS by AEC in October 1955 for personnel invited by the FCDA. The objective was to acquaint participants representing all echelons of civil defense with aerial survey techniques and equipment developed by the AEC for rapidly monitoring large water and land areas with small radiation doses for operating personnel. Instrumentation consisted of aerial radiation detection equipment and a telemetering unit to transmit data to a remote ground station. The exercise successfully demonstrated the feasibility of equipment of this type for rapidly monitoring areas contaminated with fallout radiation. Informal report by New York Operations Office.

PrePLUMBBOB (1956) Aerial Radiological Survey of the Nevada Test Site and Adjoining Areas - USGS/UCLA/DBM

In October 1956 the Atomic Energy Commission conducted an aerial survey of the NTS and adjoining areas to gather radiological information prerequisite to planning Operation PLUMBBOB 1957. At the invitation of the AEC, the Federal Civil Defense Administration joined in support of the Project.

The survey was conducted by the U. S. Geological Survey in cooperation with the AEC using DC-3 aircraft and aerial radiation detection equipment designed by the Oak Ridge National Laboratory. The Project successfully surveyed about 3400 square miles of southeastern Nevada and adjoining parts of California, about half of Utah and parts of adjoining Arizona, New Mexico and Colorado.

This survey further demonstrated the value and feasibility of utilizing aerial techniques for rapidly locating and measuring radiological contamination over wide spread land areas. Informal report by UCLA.

CEP 57.1: Radiological Assessment and Recovery of Contaminated Areas - AEC/NRDL

This exercise was conducted in December 1957 for the purpose of determining the feasibility of obtaining information on radiological countermeasures through the employment of a variety of decontamination techniques on residual radioactive material remaining on certain residential structures and ground areas at NTS and to determine the usefulness of using low level contaminated areas for orientation and training. This exercise was successfully completed and the report is in preparation. Draft manuscript is at TISE, Oak Ridge, for editing and printing.

CEP 58.1: Radiological Measurement and Evaluation of Attenuation in Typical Residential Structures - ORNL/FCDA/NBS/TL/CETO

A study was made to obtain information which could be used to evaluate the protection afforded by residences against radiation due to fallout. The sources used were Cobalt-60 and Cesium-137 and the radiation dosimeters were pocket type ionization chambers. Measurements were made for distributed sources (400 Cobalt-60 and 20 Cesium-137) and for single sources located inside the structures (one each, 2 curie Cobalt-60 and Cesium-137).

Attenuation measurements were made for five houses of typical domestic design and construction. Several modifications were made to the houses and the attenuation measurements repeated. The houses, located at the Nevada Test Site, included single and two-story wood and masonry houses, with and without basements and with "light" and "heavy" walls. For comparison with the house data, the dose rate distribution above an extended plane source was measured in a "phantom" house, i. e., air measurements with the instrument fixed on thin-walled aluminum tubing. Although the complete analysis of the data is not yet available, some results are presented in the Civil Effects Test Operation Report CEX 58.1, issued January 19, 1959.

The following is a preliminary statement of the conclusions.

1. The most effective shielding material is that which is in the direct line of radiation. For example, persons on first floors of two story wood frame houses would have an average reduction in radiation dose by about a factor of two - whereas those on first floors of two story brick houses would have a reduction of about seven.

2. Reduction of streaming of radiation through openings into basements and openings in concrete, brick or block houses increases the effectiveness of the home as a shelter. For basements of brick and wood frame houses the reduction is about a factor of thirty.

3. Kitchen and bathroom fixtures cast shadows which give additional radiation protection and location of shelter areas to include shielding from such furniture can increase the shielding potential of an ordinary house.

4. Dose rates behind chimneys and inside fire places are appreciably decreased.

5. An improved shelter consisting of a heavy table placed in the corner of a basement and covered with 7½" of concrete block provides a reduction of about 200 to 1,000.

6. The contribution of fallout on roofs of two story houses to the dose rate on the first floor is less by a factor of ten than the contribution of fallout on the ground outside.

These data are of immediate value to Federal and State agencies, builders, architects, engineers, city building officials, and technical personnel concerned with the construction of fallout protection in new homes or modifications and improvisations to improve shelter against fallout in existing homes.

CEP 58.2: Measurement of Scattering and Reradiation of Light in the Entrance to and Within Protective Shelters - U of Roch./CETO

During the later part of August 1958, at the Nevada Test Site, two existing underground reinforced concrete shelters were utilized to measure the attenuation of light as a simulant of bomb thermal radiation as it was transmitted from the entrance to the interior of the shelter.

A light source was placed outside the shelter entryway and measurements were made of the scatter and reradiation of the light at various locations in the entryway and inside the shelter. The reflective characteristics of the entryways were modified by the application of different types of paint.

The results of this project are being used in the study of thermal radiation and give an estimate of the possibility of direct thermal radiation being transmitted by reradiation into a shelter. Report in preparation.

CEP 58.3a: Plutonium Survey - Nevada Test Site - UCLA/CETO

The objective of this project was to make a thorough assessment of the plutonium content in selected local flora and fauna at the Nevada Test Site. This included studies of the existing plutonium air concentrations, plutonium content of the surface soil, and the resultant accumulated plutonium concentration in the native animal population at least one year after an explosion. These data will be correlated with that collected at Alamagordo in 1947 and later. Report in preparation.

CEP 58.3b: Resurvey of Nevada Test Site and Adjoining Areas with Special Emphasis on Strontium and Cesium - UCLA/CETO

Soil samples, native rabbits and where available milk samples were collected at 60 locations in eleven areas of Nevada and Utah along and adjacent to three fallout patterns which resulted from test devices detonated during the 1957 PLUMBBOB test series.

A report of Strontium-90 and total beta contamination in eleven areas in Nevada and Utah as of August 1958 was issued in November 1958.

CEP 58.3c: Background Survey, Jackass Flats - Nevada Test Site - UCLA/CETO

The objectives of this project were (1) to make ground and aerial surveys to establish background radiation levels before the first excursion of nuclear propulsion reactors, (2) layout study area for future soil and air sampling, collection of microflora and plants and other data pretest and (3) study local meteorology and its probable influence on fallout intensities, distribution and pattern. Report in preparation.

CEP 58-4: Aerial Radiological Monitoring Survey - USGS/CETO

The Aerial Radiological Monitoring Survey program (ARMS) started in FY 58 and is broken into three major functions: (1) aerial radiation surveying, (2) compilation of data (3) correlation of radioactivity data with geology and the preparation of reports. The immediate program is estimated to require more than three years of flying (two planes and supporting personnel) and includes:

1. Surveys of reactor sites
2. Surveys of nuclear propulsion reactor test site - NTS
3. Surveys of plowshare areas
4. Surveys of NTS as required
5. Survey of northeast quadrant of U. S. followed by surveys of other quadrants as the schedule permits. The end product will be a radiation background survey of the entire United States
6. Backup for radiological assistance plan.

The reactor sites have the highest priority. Other surveys are done at the expense of the reactor site time. Present plans include a capability to continue the ARMS program into FY 61 and later.

To date the results and immediate program are as follows:

1. Thirteen surveys completed or in progress
2. Seventeen surveys scheduled for completion by July 1, 1959
3. Fifty surveys approximately to be scheduled.

Reports are written on each site.

CEP 58-5: Radiological Survey of Heavy Structures and Shelters - TOI/OCDM/CETO

In response to a request from the Office of Civil and Defense Mobilization for assistance in finding heavy concrete or masonry structures for use by a contractor in making experimental measurements of attenuation of gamma radiation produced by exposing CO-60 as a fallout simulant, arrangements were made for access to AEC structures at NTS during December 1958. This extended the work begun under the Civil Effects Exercise 58.1 and will provide shielding information on buildings with heavy walls which can be correlated with the data from CEX 58.1. Reports will be prepared by OCDM contractor.

CEP 58.6: Radiological Survey Vehicle - EG&G/CETO

The Division of Biology and Medicine is sponsoring the development of a mobile unit for evaluating shielding afforded by conventional structures against fallout. This vehicle would provide a home owner with a means for determining the protection afforded by the house in which he lives or of other structures or shelters and give guidance to technical and professional groups for improving family protection and serve as a check on theoretical calculations.

The unit now under development is expected to establish and proof-test the optimum combination of radiation sources and instrumentation to permit maximum use of this in a normal urban community for survey of homes and other structures. It is expected that in addition to users at AEC sites, other agencies, civil defense authorities, or commercial firms may utilize this type of service on a wide scale. Report in preparation.

CEP 58-7: AEC Group Shelter Design Studies - H&N/CETO

During Operation PLUMBBOB 1957 a high-performance radiological shelter located to receive fallout was occupied without harm to personnel at zero time of several shots. This manned station represents the most significant proof-testing of a shelter component system under an actual nuclear detonation that has been accomplished to date.

As a result of these and other tests, which have demonstrated the soundness of the basic design of this type of shelter, and the possible need within the AEC organization for a fallout shelter to accommodate groups larger than a single family, the shelter is under re-design to include changes indicated by the 1957 test and to meet other requirements of a 100-person shelter for two-week occupancy. Report in preparation.

CEP 59-1: Evaluation of Radiological Protection Afforded by Modern Office Building - TOI/DBM

A radiological survey of the AEC Headquarters building was conducted in February/March 1959 to determine the shielding factors against fallout and to provide additional data on the shielding problems

related to services and utilities in a modern office building with heavy walls and basement. These data will be correlated with the results of the two previously mentioned Nevada experiments. Report in preparation.

CEP 59-2: Assessment of Environmental Contamination Emitted by Nuclear Propulsion Devices - UCLA/CETO

This project is intended to determine the extent of fallout and collect and characterize the fallout from the effluent of a nuclear power source as related to biological availability. It will also make further determination of the fate and persistence of radioactive materials in biological systems and attempt to correlate with similar data from previous tests in weapons development series. Report in preparation.

CEP 59-3: Botanical Study of Nuclear Effects at NTS - Highlands Univ. N.M.

This is a continuing study since mid 1957 of the general ecology of the Nevada Test Site area and special attention is being directed toward identifying any botanical changes which might be nuclear test connected. Preliminary report prepared and under review.

CEP 59-4: Modifications of CETG Project 32.3 Shelter for Shielding and Occupancy Studies - CETO/

This is a follow up experiment on CEP 58-7, and will include modifications as recommended by the engineering study and a field test of the shelter, using radioactive sources and deposited simulant fallout for shielding studies. It is anticipated that occupancy studies under simulated emergency conditions will be undertaken.

CEP-59-5: Static Testing of Concrete Slabs (CETG Project 34.2) Sandia

These tests are designed to yield additional information on the total capacity of reinforced concrete beams to absorb energy. The beams were first tested under dynamic blast loadings of 7 and 5 psi of a 43 Kt shot, Operation Plumbbob 1957 to compare the responses of rail and intermediate grade steel when used in reinforced concrete design.

CEP-59-6: Comparative Ecological Studies of Animals Exposed to Nuclear Radiation - Brigham Young University

This is a new project and is designed to: (1) Determine kinds and populations of animals in natural areas exposed to atomic explosions and radiation in comparison with animals in non-exposed areas. (2) Determine seasonal distribution, migration, home range and other habits of native animals in exposed and unexposed areas. (3) Establish the degree of radiation contamination of representative animals along distance transects radiating from the centers of atomic explosions. (4) Determine extent of histological changes due to radiation damage in representative vertebrates. (5) Determine the incidence of selected diseases and susceptibility of animals in exposed areas as compared to natural populations.

THE NUCLEAR ENERGY CIVIL EFFECTS PROGRAM

PART D

In addition to the current National Policy to demonstrate Federal leadership through individual agency action in support of the national civil defense plan, the AEC has a unique responsibility for self-protection because of its geographically dispersed locations, safety considerations, control of access to sensitive operations and its mission in the event of war, including applications of nuclear energy in the post-war recovery of the Nation's economy.

An effective program for AEC facilities and communities is accepted as one which places the smallest possible requirements on the manpower and other resources of the jurisdiction in which it is located. Such a program then must, while coordinated with local civil defense, include provisions for a high degree of self-sufficiency with respect to shelter, evacuation, casualty care, restoration of facilities and services, radiological defense, and post-attack recovery.

The AEC has a three-fold interest in civil defense at its various installations.

1. At all of our plants and laboratories we have a responsibility for insuring that adequate civil defense measures are taken for our employees and those of our contractors <u>while they are engaged in work at the plant or laboratories themselves.</u>

2. The AEC believes that the Commission should be concerned with the survival of its employees and those of its contractors <u>when they are not at work</u>. This may not be properly described as a responsibility of the Commission, but the Commission is concerned with the off-site situation as well as on-site because it has a direct bearing on the availability of the personnel necessary to continue the atomic energy program in time of emergency and the post-attack recovery period. There is a difference between what the Commission might be able to do in this connection as between (a) employees who are domiciled in relatively large numbers in specific and limited areas and (b) places where Commission employees are scattered widely in a much larger population group (such as Washington, D. C. or New York City.)

3. At the three installations where there are on-site communities the AEC has a special responsibility for civil defense deriving from its role in the management and government of the communities themselves.

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Program Detail - The AEC Community Civil Defense Program

Community civil defense is essentially organized self-help with operations on a local basis. The AEC is known for its competence in the development of nuclear weapons and effects data and is generally considered the appropriate agency to translate such scientific information into useful, practical procedures which can be undertaken by families and communities to achieve an enormous reduction of casualties in the event of nuclear attack. AEC can be of inestimable service in developing truly practical and economic instrumentation and communications devices and various radiological survey units, in carrying protective measures to a point of practical specifications and in mounting practical applications of these techniques at AEC locations. The program includes the following:

1. To acquaint each employee with the nature of the fallout problem in the event of a national emergency and to impress upon him his duties and responsibilities as an employee of the Atomic Energy Commission.

2. To provide a means by which the employee can ascertain the degree of protection afforded by his home shelter against fallout and other effects.

3. To provide the employee with information and guidance for improving the home protection for himself and his family against the effects of nuclear reactions.

It is proposed that this program be initiated at one or more of three locations during FY 60. The detailed program includes the following:

1. The education of the employee and his immediate family through lectures, printed media, motion pictures, and demonstrations. This is to include the education of the employees on the nature of fallout hazards and protective measures necessary; their responsibilities and relationships with AEC and to the community at large. Such material developed for use at a single location would be available for programs elsewhere. An example of simplified technical material is the draft brochure "Comparative Effects Data of Biological Interest," prepared for the AEC by the Lovelace Foundation.

2. Engineering development and procurement and/or lease operation of mobile units for surveying home, community and other structures to determine the existing radiological protection and provide guidance on measures necessary to improve the protection.

3. Engineering development and limited procurement of prototype combination radio and radiation measuring instruments for training and demonstration at AEC sites.

4. Research, development and demonstration at AEC locations of homes, community and plant emergency shelters appropriate to the agency role in national emergencies.

The Group or Community Shelter

During the 1957 test series at the Nevada Test Site, the Atomic Energy Commission sponsored an experiment in which a 25 x 48 foot underground shelter was manned by about 15 selected persons at the time of several detonations to collect data which would lead to improved criteria for protection against fallout. This shelter, which is of sufficient size to accommodate 100 persons for prolonged periods, provided as installed at the Nevada Test Site, protection against overpressures of 4 psi and reduced the radiation intensity by a factor of 10,000.

An AEC contractor is preparing scale drawings, outline specifications, and a bill of material in such detail as to permit local builders to prepare cost estimates on the shelter for construction in any part of the country. Included in the overall plan is also a brochure which will give pertinent facts to management on the structure. There has been prepared in draft form a list of supplies and equipment required to make the shelter tenable for a minimum period of 14 days for 100 persons.

Although the primary purpose of this activity is to develop a relatively economical structure for the protection of personnel at AEC facilities, the final product will be immediately adaptable to any group requiring a protective facility.

There is little knowledge on the response of people to prolonged occupation of a shelter, and consideration is being given to a project to develop information on human behavior patterns as they appear over the course of a week or longer in a closed shelter. The existing shelter at NTS may be modified and utilized for this purpose.

Evaluation of Shielding

During 1958 the AEC conducted an experiment at the Nevada Test Site to determine the shielding afforded by typical residential structures. The technique employed a large number of Cobalt-60 sources arrayed in such manner as to simulate the radiation field of fallout. Results, which have been published in an unclassified report, CEX 58.1, were excellent and indicate not only the value of these experimental measurements in improvement of shelter in existing homes but also in the design of new homes.

A similar technique has been employed to evaluate the radiation protection afforded by the AEC Headquarters building in Germantown, Maryland. It is to be anticipated that the results of this latter study will be of use in evaluating the fallout shelter existing in multi-storied buildings and point toward practical modifications which will enhance the protection. These data will also be valuable to architects and engineers in the design of new structures.

Citizens' Instrument

In order to take proper action in a contaminated zone, an individual must have information on the radiation hazard in his environment. In the civil defense situation one source of this information is broadcast radio over which official civil defense announcements will be made. The other source is a radiation detection and measuring instrument either in the hands of radiological defense personnel or the family itself.

Prototype combination radio-radiation detectors have been developed through the AEC to put in the hands of the family one instrument to serve the two purposes. To a conventional portable transistorized radio there has been added a radiation detector by means of which the degree of the local hazard may be appraised. On the basis of this appraisal, individual or family decisions with respect to the action to be taken at various times post-attack may be made with reasonable assurance of avoiding inadvertent, casualty-producing overexposures. This will be particularly true at times when circumstances or desires favor moving from a sheltered location.

The Atomic Energy Commission in 1957 obtained four experimental models of prototype instruments. It has now received delivery on an order for 25 instruments of one possible model which will be circulated among interested persons in and out of the AEC. On the basis of comments recommendations will be made with respect to further development of these units. It is to be hoped that ultimately the manufacturers of electronic equipment will undertake the commercial development and marketing of these types of instruments.

Radiological Survey Vehicle

In order to extend to home owners the benefits of the technique which employ radioactive sources to simulate a fallout field, there was assembled during the 1958 experiment at the Nevada Test Site preliminary information on the design of a survey vehicle. The development of this has been assigned to an AEC contractor, and it is anticipated that the first test vehicle will be ready in late May 1959. Plans call for trial runs to be made at NTS using the typical residences surveyed in CEX 58.1 for test purposes. These trial runs are intended to prove out the technique and lead to the refinement of procedures for deploying the sources and measuring instruments and establish safe operating procedures.

The radiological survey vehicle in practical application will provide for a collection of measurements in individual homes. From an analysis of the measurements, technicians will be able to point out to the home owner the safest place in the house and to suggest means for further improving the available protection against fallout radiation. By this means the nucleus of a home protection plan will have been established.

We anticipate that this vehicle will be used in the AEC and other community civil defense programs.

Prompt-Gamma and Neutron Studies

The Ichiban program in prompt-gamma and prompt-neutron radiation studies will be continued at ORNL and NTS using reactors and other radiation sources to study shielding of typical Japanese structures. Through liaison arrangements between AEC-NAS/NRC-ORNL-ABCC these data are being correlated with the field data being collected by the Atomic Bomb Casualty Commission. Also, the work is being coordinated with the Los Alamos Scientific Laboratory and School of Aviation Medicine, USAF, two other laboratories which have a primary interest in the program.

Residual Radiation and Fallout Studies

The fallout study and documentation program which started in 1947 will be continued on-site at NTS and Alamagordo and in nearby areas for correlation with previous work. Emphasis will be placed on establishing isodose contours, correlating ground readings with aerial readings, correlating particle size with activity and distance from point of detonation, documenting plant and animal uptake and correlating with physical and chemical parameters and gathering other data which are required in botanical and biological evaluation of the effects of fallout on people, flora, fauna and land areas. This activity will also support an expanded ecological program.

Aerial Radiological Monitoring Survey

The Aerial Radiological Monitoring Survey program is broken into three major functions: (1) aerial radiation surveying; (2) compilation of data and (3) correlation of radioactivity data with geology and the preparation of reports. The immediate program is estimated to require more than three years of flying (two planes and supporting personnel) and includes:

1. surveys of reactor sites,
2. surveys of nuclear propulsion reactor test sites,
3. surveys of plowshare areas,
4. surveys of NTS as required,
5. survey of northeast quadrant of the U. S. followed by surveys of other quadrants as the schedule permits,
6. backup for radiological assistance plan.

Civil Effects Test Operations

In August 1958 the Division of Biology and Medicine established at NTS the Civil Effects Test Operations Office to coordinate and direct projects approved by the DBM and CETG, activities which are conducted at the Nevada Test Site during and between nuclear tests. In early 1958 a capability to utilize the NTS to progress our knowledge through non-nuclear tests and experiments had been developed and demonstrated.

It is planned to continue the CETO office at NTS and to accelerate selected field tests and experiments in extension of theoretical and

laboratory work. Emphasis will be directed principally to practical applications and to obtaining information on environmental effects of blast, thermal and nuclear radiation for the purpose of filling gaps in knowledge and defining biologically acceptable conditions for human habitation.

Biomedical Effects Studies

In support of the individual agencies and the national non-military defense programs there is a requirement for continuing scientific and technical investigation of the effects of nuclear detonations on man.

More than two years planning has gone into a cooperative program comprising the AEC, DOD, OCDM, DHEW, D/Agriculture, D/Commerce, and Veterans' Administration. The program was conceived to fill an urgent need for the further development of knowledge on the biomedical and associated effects of nuclear weapons.

The AEC, through the DBM, has accepted the role of executive agency and has provided the leadership for the further development of this program. Task Units have been organized to consider the state of knowledge, identify urgent needs and recommend methods for obtaining the information to meet the needs as a first step in the determination of program content of future effects programs. Task Units have met to consider ecological studies, blast biology, thermal biology, radiation countermeasures and decontamination, and fallout.

To understand and evaluate the results of field experimental programs involving nuclear reactions, substantial laboratory investigations must be done. Through such a laboratory program we may reduce the number and complexity and hence the uncertainties of the field experiments and develop substitutes for nuclear detonations in new studies and extension of previous field experiments.

The need for a biomedical test program and supporting laboratory work has been based on a requirement for information. Whatever course the weapons testing program may take, the requirement for the information will persist.

PART E

COMPARATIVE EFFECTS DATA FOR SURVIVAL MEASURES

An evaluation of the information on weapons effects already available in the open literature has shown that there is substantial information of practial value already published, which can be used in building a national self-protection program. Unfortunately these data are not contained in a single publication and are therefore not in the most usable form for practical application.

The nation has made considerable progress in developing plans and equipping Federal, state, and city organizations, which would be ready to aid in case of enemy attack. However, it is known that it is not possible for the government to provide absolute protection to all its citizens in case of a nuclear war. It is important that citizens realize that if a nuclear war starts, many Americans will be casualties. Studies have shown that there is substantial fallout protection already available in the nation and the total number of casualties can be greatly reduced if people apply the information now known on protection against weapons effects. In order to appreciate the problem it should be remembered that the weight of attack being considered for these hearings of 1453 MT could subject 10 to 14 percent of the land area of the U. S. to blast pressures of about 1 psi, and generate thermal radiation which would produce 1st degree burns over a large area. It has been estimated that in an all out nuclear war about 1 psi blast pressure and thermal radiation sufficient to produce more than 1st degree burns might blanket the entire country.

Fortunately, there are some things which can be done about these effects. But before considering palliatives and remedies lets examine comparable risks in everyday life. The reason for suggesting this approach is that people do not react well to LD 50 concepts which are often used as the basis for estimating casualties from nuclear weapons effects. LD 50 by definition, means that a lethal dose of an effects is predicted for 50% of those exposed to it. Unfortunately, LD 50 concepts do afford a convenient out for anyone who prefers the status quo in day-to-day arrangements of his personal life and therefore can conclude that he is either in the 50% dead of 50% live. So, why do anything about it?

It may be better to start with a threshold effect which is comparable in risk to our daily activities such as driving an automobile through traffic, walking across a busy thoroughfare or what one does do to avoid burning down the house in which he lives. For instance, if it is agreed that one psi blast pressure is acceptable as such threshold because such blast loading does not do structural damage but only fragments glass and other friable materials or damages non-structural parts of the house in which one lives and is preceeded by a sudden warning burst of light, then is it not logical to arrive at similar thresholds of risk for thermal energy in

calories per centimeter square and "r", rem or rads--they are all the same for these purposes--in prompt radiation and a number in "r", rem or rad for residual or fallout radiation? From such decisions one can proceed from a realistic base to improve his protection against any effect commensurate with his desire and economic feasibility. The decision on improved protection for his family and himself is reached through the same rationalization by which a man decides how much insurance he should carry on himself, on his house, on his automobile. What can be done is a personal decision; but the direction in which to go is clear.

Some time ago it was recognized that it was not sufficient for the AEC to merely run experiments, collect and evaluate data, and publish these in reports. Additional efforts are needed to make this information usable by the public. Dr. Clayton S. White and Mr. I. G. Bowen of the Lovelace Foundation for Medical Education and Research, working under an AEC contract, have been working on a brochure on "Comparative Effects Data of Biological Interest". This is still in draft form but some of the tables and charts have been extracted to illustrate the type of information which it is believed to be needed by the citizens of this country for planning their self-protection against nuclear war. This is also needed by governmental officials and others responsible for planning and implementing a program to meet the problems of surviving and reducing the effects of nuclear detonation.

It is necessary that the individual citizen evaluate for himself the kind and degree of protection best suited to his needs. It is most important for an individual home owner to be able to evaluate the protection available to him in his own home and to exercise his judgment on the risk he is taking and to know how he can improve his chances of survival. As an example, assume that a man lives about 25 miles from a city and there are no other important industrial or military targets nearby. From a 20 MT bomb, depending upon wind direction, type of burst, i.e. air or surface, this man could expect fallout dosages upwards of 3000 r/hr, blast pressures of about one psi and thermal radiation of about 8 cal/cm^2. He would be beyond the range of the prompt neutron and gamma radiations. What does this mean in terms of hazard to the man and his family? Prolonged exposure without protection to 3000 r/hr would give an estimated infinity dose of 19,800 r and be fatal within a relatively short period of time. The blast pressure will shatter most windows and superficially damage a woodframe house. The thermal injury to anyone who was unprotected and was facing toward the detonation would be characterized by second degree burns and some eye injury. Survival depends on how much this man has found out about weapons effects and precautions he needs to take. It has been learned from studies that a basement in an ordinary two-story brick house provides a shielding factor of about 30 against fallout; and an improvised

concrete-block shelter in the basement will increase the shielding factor to about 1000. This means that the fallout dose can be reduced to the order of about 20 r, lifetime dose and only about 13 r, recieved in the first 2 days in the shelter. Several of the survivors of nuclear accidents have sustained doses greater than 100 r. Measures taken to protect against fallout only at this distance would automatically protect in some degree against blast and thermal effects. Therefore, one could expect to have a high probability of survival from a burst some 25 miles away if he had an adequate home shelter in the basement of his home.

The data used to prepare the aforegoing brief analysis were extracted from the 10 April 1959 draft brochure prepared by Dr. White and Mr. Bowen. The following tables and charts are typical of the type of information which will be contained in the final document. These along with the accompanying text have been reproduced here by permission of the authors. The data contained in these tables and charts are the type of information which is needed by a citizen to assess the risks he faces and for making the judgments on the degree of protection he will need.

Table 1

PROBABLE EFFECTS IN HUMANS OF ACUTE EXPOSURE TO IONIZING RADIATION OVER THE WHOLE BODY

Acute dose r	Probable Effect
0 - 25	No obvious injury.
25 - 50	No serious injury. Possible blood changes.
50 - 100	Blood cell changes, some injury. No disability.
100 - 200	Injury, possible disability.
200 - 400	Injury and disability certain, death possible.
400	Fatal to 50 per cent.
600 or more	Fatal.

Data from Radiological Health Handbook, U.S. Department of Health, Education and Welfare, citing The Effects of Nuclear Weapons as the source of the information.

Table 2

ESTIMATED CLINICAL COURSE AND HOSPITALIZATION REQUIREMENTS FOR HUMANS EXPOSED TO VARIOUS ACUTE DOSES OF PENETRATING RADIATION

Dose in r	Percent individuals following indicated clinical symptoms						Percent needing hospital-ization	Maximal time of hospitali-zation weeks
	trivial	light	moderate	serious	grave	fatal		
0 - 200	98	2					none	0
200 - 300	1	33	64	2			2	6
300 - 400			6	68	26		94	7
400 - 500				3	58	39	100	9
500 - 600					6	94	100	11
above 600						100	100	11

Compiled from Gerstner

Table 3

In Table 3 are tabulated the approximate ranges from ground zero and the circular areas over which the indicated selected weapons effects may occur as a function of explosive yield. It was assumed that slant ranges for initial ionizing radiation and thermal data are a reasonable approximation of the ground range and that atmospheric conditions were clear.

Table 3

COMPARATIVE WEAPONS EFFECTS DATA

Explosive Yield	1 KT	20 KT	100 KT	1 MT	10 MT	20 MT
Range (mi) from Ground Zero for Various Parameters						
700 rem (Initial)	0.42	0.70	0.96	1.44	2.04	2.27
100 rem "	0.62	0.99	1.29	1.81	2.55	2.88
30 rem "	0.74	1.18	1.51	2.07	2.91	3.30
5 PSI (Typical Air Burst)	0.39	1.06	1.81	3.90	8.40	10.6
5 PSI (Sfc Burst)	0.28	0.77	1.32	2.85	6.14	7.74
1 PSI (Typical Air Burst)	1.00	2.71	4.64	10.0	21.5	27.1
1 PSI (Sfc Burst)	0.86	2.35	4.02	8.65	18.6	23.5
Second Degree Burns	0.48	1.72	3.40	9.00	23.8	31.9
First Degree Burns	0.69	2.47	4.97	13.3	36.0	49.2
Area (sq mi) Corresponding to Above Ranges						
700 rem (Initial)	0.55	1.54	2.90	6.51	13.1	16.2
100 rem "	1.21	3.08	5.23	10.3	20.4	26.1
30 rem "	1.72	4.37	7.16	13.5	26.6	34.2
5 PSI (Typical Air Burst)	0.48	3.53	10.3	47.8	222	353
5 PSI (Sfc Burst)	0.25	1.86	5.47	25.5	119	189
1 PSI (Typical Air Burst)	3.14	23.1	67.6	314	1450	2310
1 PSI (Sfc Burst)	2.32	17.4	50.8	235	1090	1730
Second Degree Burns	0.73	9.29	36.3	254	1780	3200
First Degree Burns	1.50	19.2	77.6	556	4070	7600

Data from The Effects of Nuclear Weapons

Table 4

Table 4 gives the approximate ground ranges in miles for selected values of initial ionizing radiation, overpressure and thermal radiation computed for typical air bursts of indicated yields assembled in such a way as to aid appreciation of the interrelation between the individual effects. For example, a ground range of about 3 miles is shown for 100 rem initial radiation from a 20 MT detonation at which distance an overpressure of near 19 psi can be expected along with a thermal load of over 1000 cal/cm^2. Ten miles from ground zero 1 psi is predicted for a 1 MT explosion at which location there would occur less than 10 rem and about 6 cal/cm^2 of initial ionizing and thermal radiation, respectively. Referring to the bottom of the table, one can see that 6 cal/cm^2 of thermal energy is sufficient to produce second degree burns to the exposed bare skin.

Since the data in Table 4 are for typical air bursts, no significant short term fallout hazard would occur. As in the previous table, slant ranges for ionizing and thermal radiations were considered to be a reasonable approximation of the ground range.

The symbols > and >> mean "greater than" and "much greater than", while < and << mean "less than" and "much less than", respectively.

Table 4

COMPARATIVE EFFECTS DATA OF BIOLOGICAL INTEREST

Explosive Yield	1 KT	20 KT	100 KT	1 MT	10 MT	20 MT
30 REM Range, mi	0.74	1.18	1.51	2.07	2.91	3.30
Pressure, psi	1.70	4.16	6.60	11.1	15.6	17.0
Thermal, cal/cm^2	1.70	12.4	36.0	182	880	>1000
100 REM Range, mi	0.62	0.99	1.29	1.81	2.55	2.88
Pressure, psi	2.30	5.55	8.30	12.4	17.4	18.8
Thermal, cal/cm^2	2.50	18.0	52.0	240	>1000	>1000
1 PSI Range, mi	1.00	2.71	4.64	10.0	21.5	27.1
Radiation, REM	<10	<10	<10	<10	≪10	≪10
Thermal, cal/cm^2	0.88	2.02	3.30	5.90	11.4	13.8
5 PSI Range, mi	0.39	1.06	1.81	3.90	8.40	10.6
Radiation, REM	900	64	<10	<10	<10	<10
Thermal, cal/cm^2	7.00	15.8	24.5	46.0	89.0	105
Second Degree Burn						
Range, mi	0.48	1.72	3.40	9.00	23.8	31.9
Pressure, psi	3.6	2.2	1.7	1.2	<1	<1
Radiation, REM	380	<10	<10	<10	≪10	≪10
First Degree Burn Dose, cal/cm^2	2.0	2.5	2.7	3.2	3.7	3.8
Second Degree Burn Dose, cal/cm^2	4.1	4.9	5.4	6.2	7.2	7.5
Third Degree Burn Dose, cal/cm^2	6.0	7.3	8.1	9.4	10.8	11.4

Data from The Effects of Nuclear Weapons

Table 5

Table 24 presents approximate comparative effects data for a surface burst of 20 MT total yield. The presence of fallout radiation is the principle difference between this type of explosion and one detonated in the air. Ranges for the 1 and 5 psi lines are somewhat shorter for the surface burst compared with the air burst.

Assumptions made in computing the fallout pattern were (1) an effective wind of 15 mph, and (2) 50 per cent of the total yield was derived from fission. The latter assumption was necessary since the fusion process does not contribute significantly to the radioactivity of the fallout.

The somewhat hypothetical "1 hour reference dose rates" in roentgens per hour were used as a means of illustrating the relation between the fallout hazard within the immediate target area and the blast, radiation and thermal effects. The 1 hour reference dose rate is defined as the dose rate 1 hour after the detonation assuming that the fallout were complete at that time. The somewhat artificial significance of these dose rates in terms of accumulated dose is discussed in connection with Table 6.

The symbol > means greater than, while < means less than.

Table 5

COMPARATIVE EFFECTS DATA FOR A 20 MT SURFACE BURST

	Range (mi)	Area (mi^2)
>First Degree Burns	49.2	7600
>Second Degree Burns	31.9	3200
>Third Degree Burns	29.0	2640
>1 PSI	23.5	1730
>5 PSI	7.74	189
>30 REM (Initial)	3.30	34.2
>100 REM (Initial)	2.88	26.1
>30 R/hr Fallout (1 hr Reference Dose Rate)		2180*
>100 R/hr " " " " "		1400*
>300 R/hr " " " " "		1090*
>1000 R/hr " " " " "		851 *
>3000 R/hr " " " " "		515 *
>1 PSI, <30 R/hr		357
>1 PSI, <100 R/hr		1010
>Second Degree Burns, <1 PSI		1460
>Second Degree Burns, <30 R/hr		1680
>Second Degree Burns, <100 R/hr		2370

*Measured only to First Degree Burn Line.
Effective wind assumed to be 15 mph.

Data from The Effects of Nuclear Weapons

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Table 6

Table 6 shows the exposure dose rate and accumulated dose from penetrating radiations as functions of the time after detonation and selected 1 hour reference dose rates in unprotected locations. Accumulation of radiation dose was calculated starting at 15 min after the detonation. It is well to note that were a shelter equivalent to 3 ft of earth available, the exposure doses within the shelter would be approximately 1/1000 of the exposure doses tabulated in the body of the table.

Two examples will be given of ways Table 6 might be useful to crudely approximate accumulated dose from penetrating fallout radiations.

Example 1. Assume that an individual were exposed to fallout radiations near the 1000 r/hr 1 hr reference iso-dose rate line shown in Figure 3. This person, if unprotected, would have accumulated approximately 1600 r at the end of the first hour after detonation (see table). Such a value assumes that the fallout was complete at this location in question within 15 min after the burst. At the end of 1 hr after the explosion the dose rate would be 1000 r/hr. At the end of the second hour, Table 6 shows that the exposure dose rate would have dropped to near 435 r/hr and the total accumulated dose would be 2250 r. If, on the other hand, the fallout was not complete until 1 hr after detonation, then the total accumulated dose would be near 650 r shown in parentheses in Table 6 which gives the difference between the accumulated doses shown for 1 hr (1600 r) and 2 hrs (2250 r). Of course, such exposures would be fatal, but were a fallout shelter giving radiation attenuation of 1 in 1000 (3 ft of earth) available and used, the accumulated doses would have been 1.6, 2.25 and 0.65 r instead of 1600, 2250 and 650 r for the examples considered above.

Example 2. Assume an individual survived the burst by taking shelter and 6 hrs after the burst he measured an exposure dose rate of 128 r/hr outside the shelter. By locating this dose rate in Table 6 the individual knows his shelter was near the 1000 r/hr 1 hr reference dose rate contour, but more important he notes the figure (460) in the table which tells him he would accumulate 460 r were he to leave the shelter for the next 6 hrs.

Table 6

ACCUMULATED RADIATION DOSE AND DOSE RATE AS A FUNCTION OF 1 HR REFERENCE DOSE RATE AND TIME AFTER DETONATION

1 hr Ref. Dose Rate:		30 R/hr		100 R/hr		300 R/hr		1000 R/hr		3000 R/hr	
Time after detonation		Dose* r	Dose rate r/hr	Dose* r	Dose rate r/hr	Dose* r	Dose rate r/hr	Dose* r	Dose rate r/hr	Dose* r	Dose rate r/hr
1 hr		47.9	30.0	160	100	479	300	1600	1000	4790	3000
	(1 hr)+	(19.5)+		(65)		(195)		(650)		(1950)	
2 hrs		67.4	13.1	225	43.5	674	131	2250	435	6740	1310
	(2 hrs)	(16.8)		(56)		(168)		(560)		(1680)	
4 hrs		84.2	5.68	281	19.0	842	56.8	2810	190	8420	568
	(2 hrs)	(8.9)		(29)		(89)		(290)		(890)	
6 hrs		93.1	3.49	310	12.8	931	34.9	3100	128	9310	349
	(6 hrs)	(13.9)		(46)		(139)		(460)		(1390)	
12 hrs		107	1.52	356	5.07	1070	15.2	3560	50.7	10700	152
	(12 hrs)	(11.0)		(39)		(110)		(390)		(1100)	
24 hrs		118	.662	395	2.21	1180	6.62	3950	22.1	11800	66.2
	(12 hrs)	(7.0)		(20)		(70)		(200)		(700)	
36 hrs		125	.407	415	1.36	1250	4.07	4150	13.6	12500	40.7
	(12 hrs)	(4.0)		(14)		(40)		(140)		(400)	
48 hrs		129	.269	429	.96	1290	2.69	4290	9.6	12900	26.9
		(69)		(231)		(690)		(2310)		(6900)	
Infinity Dose		198		660		1980		6600		19800	

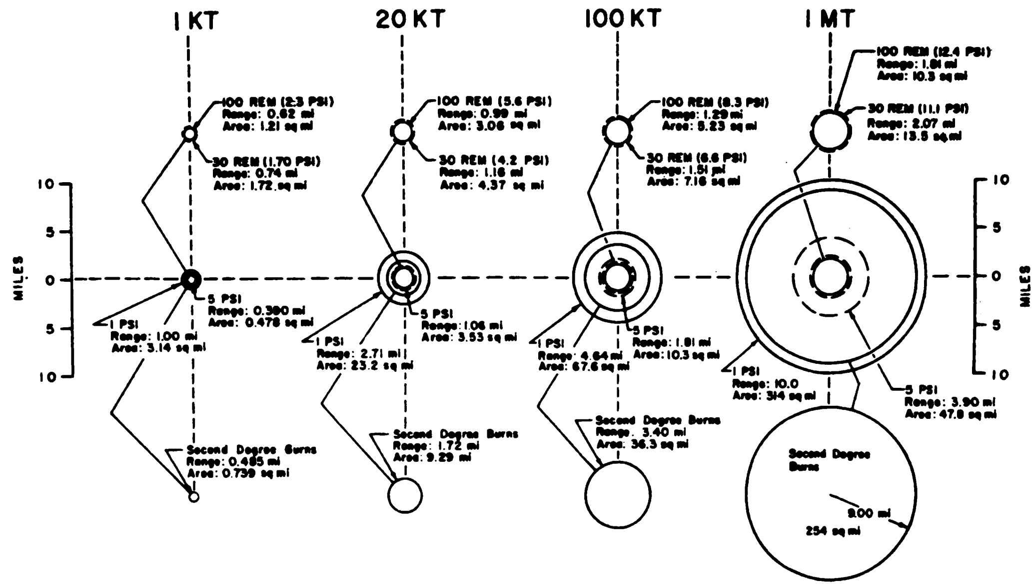
*Doses computed starting at 15 min after detonation.
+Numbers in parentheses represent differences between adjacent values.

Data from The Effects of Nuclear Weapons

Figure 1

The scaling relations for 30 and 100 rem initial radiation, 1 and 5 psi, and second degree burns are shown to the same scale in Figure 2 for typical air bursts ranging from 1 KT to 1 MT. The reader will note that the 100 rem radius extends well beyond the 5 psi line for a 1 KT yield. These two radii are almost equal for the 20 KT, but the 5 psi line extends much beyond the 100 rem range for yields of 100 and 1000 KT. Slant range for ionizing and thermal radiation was considered a fair approximation of the ground range.

Figure 1



Environmental Variations due to Blast, Thermal, and Initial Ionizing Radiation for 1, 20, 100, and 1000 KT Explosive Yields
(Data from Effects of Nuclear Weapons)

Pressure data are for typical air bursts.
Slant Ranges shown for Ionizing and Thermal Radiation

Figure 2

Figure 2 summarizes graphically the yield-distance relationships for effects produced by typical air bursts and allows comparison of the ground ranges for 30 and 100 rem initial radiation, 1 and 5 psi and first and second degree burns. It was assumed that clear weather conditions prevailed and that slant range for ionizing and thermal radiation represented a reasonable approximation of the ground range.

Figure 2

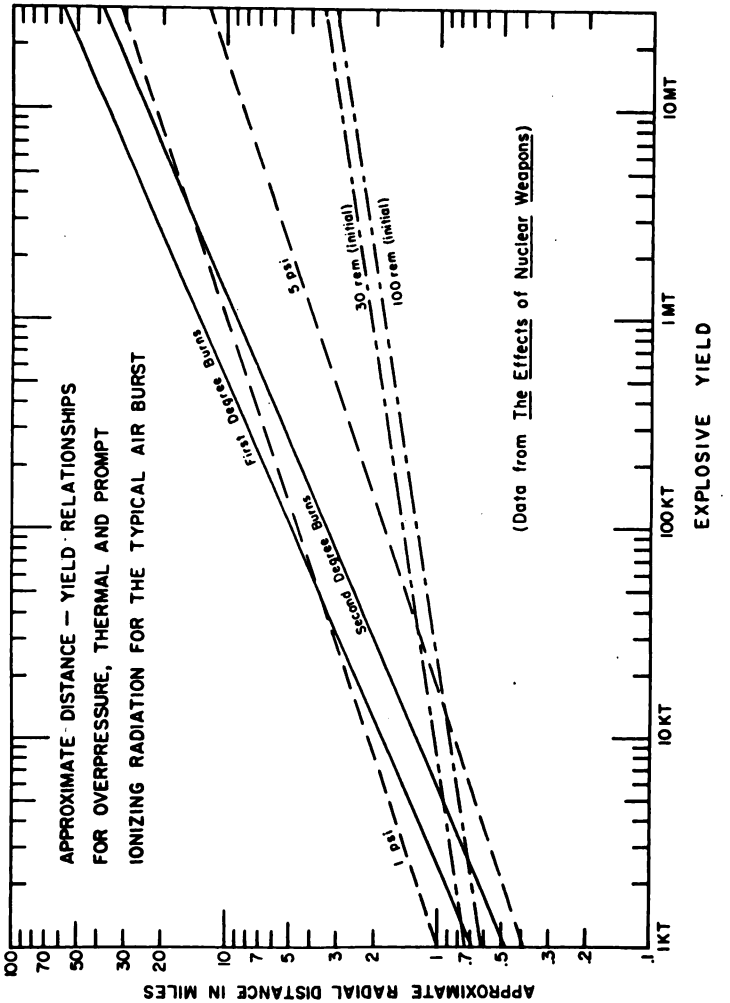

APPROXIMATE DISTANCE — YIELD RELATIONSHIPS
FOR OVERPRESSURE, THERMAL AND PROMPT
IONIZING RADIATION FOR THE TYPICAL AIR BURST
First Degree Burns
Second Degree Burns
1 psi
5 psi
30 rem (initial)
100 rem (initial)
(Data from The Effects of Nuclear Weapons)
APPROXIMATE RADIAL DISTANCE IN MILES
100
70
50
30
20
10
7
5
3
2
1
.7
.5
.3
.2
.1
1KT
10KT
100KT
1MT
10MT
EXPLOSIVE YIELD

Figure 3

Figure 3 graphically presents the effects data set forth in Table 5 referable to a surface detonation of a nuclear weapon having an assumed fission yield of 10 MT but a total yield of 20 MT.

The somewhat hypothetical fallout contours in terms of the 1 hour reference dose rates are depicted only to the first degree burn limit approximately 49 miles from ground zero although the fallout might actually extend several hundred miles from the target area as dictated by the winds aloft. In the illustration a 15 mph effective wind was assumed.

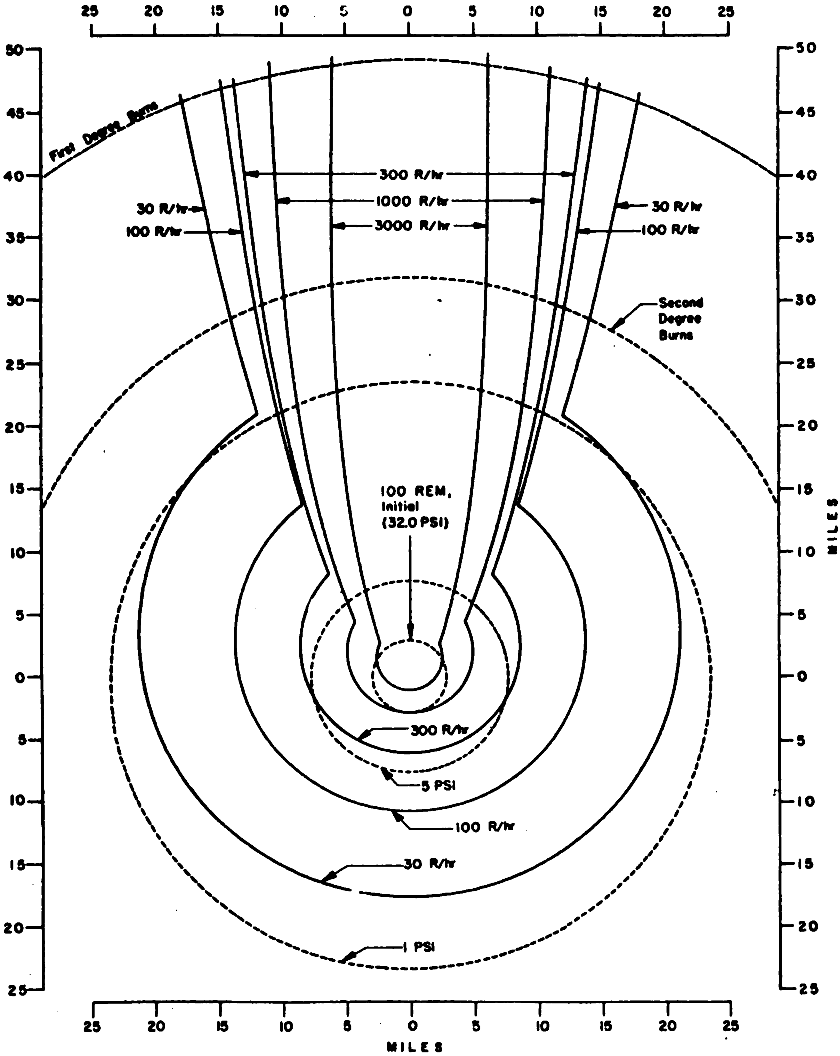


Figure 3

COMPARATIVE EFFECTS FOR A 20 MT SURFACE BURST

Residual radiation data — one hour reference dose rates — computed for a fission yield of 10 MT and an effective wind of 15 mph

Representative HOLIFIELD. We will adjourn now until 2 o'clock this afternoon.

(Thereupon, at 12:40 p.m., the subcommittee was recessed, to reconvene at 2 p.m., the same day.)

AFTERNOON SESSION

Representative HOLIFIELD. The committee will be in order.

We will begin testimony this afternoon on environmental contamination resulting from nuclear war.

We will consider the following categories of environmental contamination:

1. Effects on animals.
2. Effects on soils and crops.
3. Effects on foods.
4. Experimental results of long-term effects.
5. Long-range implications.

Our first witness is Dr. Bernard Trum, director of the Animal Research Center of Harvard University Medical School.

Dr. Trum has had years of actual field and laboratory experience in conjunction with the AEC on the effects of radiation on animals.

Dr. Trum, we are happy to have you before us. You may proceed.

STATEMENT OF BERNARD F. TRUM,[1] D.V.M., DIRECTOR OF THE ANIMAL RESEARCH CENTER, HARVARD UNIVERSITY MEDICAL SCHOOL

Dr. TRUM. Thank you very much.

I appreciate the privilege of presenting this statement before the subcommittee, and although I shall limit my remarks to the effects of nuclear radiation on animals, I take the opportunity to express the deep interest of myself and my professional colleagues in veterinary medicine to the relation of this effect to man. However, that will not be a part of this paper.

The cattle of Alamogordo, as you know, were the first casualties

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New York State Veterinary College, Cornell University, 1935 (D.V.M.).
Veterinary Corps, U.S. Army, 1935–58.
Professor of zootecnia, University of San Simon, Cochabamba, Bolivia, 1949–50.
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Representatve from American Veterinary Medical Association to the National Committee on Radiation Protection and Measurements.
Director, Animal Research Center and lecturer on Veterinary Medicine in the Department of Pathology, Harvard Medical School, Boston, Mass., 1958 to present.

of nuclear warfare, and one of the first industrial hazards from the use of nuclear radiation was the Windscale incident, which involved the passage of radiation through the cattle, through the milk, to people.

All ionizing radiation, produces its effect when it is absorbed, as you well know. A quantity of radiation of specific quality produces similar effects, regardless of the source; so that the animals experimentally exposed to a P–32 plague, cobalt–60, Sr–90, or from the bomb tests themselves, can be used directly in extrapolating to that which can be expected from nuclear warfare.

At this time I should like to offer a prepared statement, which I shall summarize and from which I shall draw certain conclusions.

Representative HOLIFIELD. Your statement will be accepted in its entirety.

(The prepared statement referred to follows:)

STATEMENT TO SPECIAL SUBCOMMITTEE ON RADIATION OF THE JOINT COMMITTEE ON ATOMIC ENERGY

By

Bernard F. Trum, D.V.M.

I appreciate the privilege of presenting this statement before the subcommittee on radiation. Although I shall limit the remarks on the effects of nuclear radiation on animals, I take the opportunity to express the deep interest of myself and a large segment of the veterinary profession in the relation of these effects to man. The cattle of Alamogordo were the first casualties of fallout from nuclear war and their beta burns the first lesions. The first major public health problem from industrial use of nuclear energy, the accident at Windscale, was important because authorities wished to prevent the contamination of the public through the milk of the dairy cow.

Effects are produced when ionizing radiation is absorbed. A quantity of radiations of specific quality produce similar effects regardless of the source of radiation. Therefore data derived from field tests, exposure to Co-60, contacts with P-32 plagues, or the ingestion of Sr-90 are equally useful in describing that which can be expected from nuclear warfare. At this time I should like to offer a prepared statement* which I shall summarize and from which I shall draw certain conclusions.

In this statement I point out that all domestic animals have a similar response to total body irradiation (table I); none are significantly more or less resistant or sensitive. Few if any die after exposure to 250r and few survive a dose as high as 1000r. Slower dose rates or fractionated doses are tolerated better than faster delivered acute doses (table II, III, IV). Some animals like the swine have a much more rapid recovery rate than others like the burro although there is little difference between the response of the species to an acute exposure . The response of the animal may vary with the quality of radiations and other things being equal the relative biological effectiveness of X or Y radiation is related to the linear energy transfer of the photon (table V, VI).

The body size of the animal has little to do with survival although the very young or the very old may be more radiosensitive.

*
Abstracted and updated from Radiation Injury by Bernard F. Trum and John H. Rust. Reprinted from Advances in Veterinary Science, Volume IV, Academic Press Inc., New York, 1958.

There is no single clinical reaction for irradiation damage in animals. Complete collapse of the burro to an acute exposure in low lethal range is unique but may be observed in most other animals if high exposure doses are given rapidly. Following an exposure there are usually days of good health, this is followed by four or five days of apathy, followed by increased irritability, hyperesthesia, decreased food and water intake and finally death or recovery. Animals usually die or recover within three or four weeks. There is always a latent period between irradiation and death.

Animals experimentally exposed to X or Y rays of high energy (0.5 to 2. mev) have not had alopecia as did goats and burros exposed to radiations from nuclear detonations. This loss of hair is not to be confused with the beta burn.

The characteristic blood picture of the irradiation syndrome in animals is: immediate decrease in numbers of circulatory lymphocytes; a lesser and slower reduction and faster recovery of polymorphonuclear leukocytes and erythrocytes; a slower clotting time and impaired clot retraction. Leukemia has been observed following total body irradiation of swine.

The immune response of animals to parasites and disease is affected by total body irradiation. Active immunities have been completely destroyed, however the response to the immunity of viruses, toxins or bacteria is not always similar.

There are no distinctive effects of irradiation on the reproductive system, only incremental changes are manifest. Doses in the lethal range are necessary to impair fertility. Lower exposures, at the proper time in gestation, may cause fetal aberations. Genetic changes can be assessed only when there is a well known background mutation rate in animals and then will not necessarily be deleterious due to the common practice of selective breeding.

Radionuclides in sufficient quantity within the body produce a total body irradiation syndrome. The phenomenon has been observed in the sheep and dogs due to injected doses. Concentration of strontium and iodine have produced neoplasms in domestic animals. The thyroids of cattle contain much higher concentrations of radioiodine from nuclear detonation and reactors than do the thyroids of man.

Many suggested maximum permissible levels of body burdens for radionuclides in animals have been proposed. For the most part they are not based on the effect on the animal but as a limitation to the concentrations passed on to man through animal products such as milk. Where maximum permissible levels for animals have been suggested, the concentrations suggested seem to occur under conditions which at the same time would have produced hazardous total body irradiation.

Particulate matter in fallout has lodged sufficient radioactive material in the coats of grazing animals close to nuclear detonations to produce beta-

burns in the hides. These lesions are characterized by epidermal atrophy, dyskeratosis and necrosis depending upon the severity. They may heal completely, leave a smooth weakened skin with discolorised hair, or form permanent scar tissue. Experimentally it takes thousands of rads of beta-radiation to cause a beta burn. None of the animals accidentally exposed and observed have had other physical signs of exposure.

From data contained in the reports of this subcommittee on radiation and reports of the New York Operations of the Atomic Energy Commission we have noted that animals in relatively heavy concentrations of radiocontamination such as the test sites in Nevada or Rongelap, did not assimilate proportionally higher concentrations of Sr-90 over a period of two years, when comparisons were made of world wide strontium levels. Factors other than absolute concentration seem to have been operating.

Limited experimental evidence and field testing indicate that animals in the path of a fallout which fail to develop beta burns will have been exposed to less than harmful external radiation and the radionuclides from that cloud will be practically innocuous to the grazing animal.

Animals that sustain exposure intense enough to produce beta burns but live longer than three weeks or a month fall into the same category as those without burns.

All other grazing animals will have received a fatal total body exposure dose and both external beta irradiation and irradiation from ingested sources are of no consequence.

It is theoretically possible to produce an area of high radiocontamination by overlapping non-simultaneously arriving fallout. In such a case there would be no beta burns on the hide of animals but deaths would be due to total body irradiation from ground concentrations or the ingested mass. Otherwise the radiocontamination will be of little consequence to the animal.

It is suggested that the limiting factor for survival following a nuclear attack will be man and not the animal. The use of animals and animal by-products may reduce the hazard of radiocontamination following nuclear warfare below that which must be tolerated if food is obtained directly from plants. Although total body irradiation and intestinal doses from absorbed isotopes will be much higher for animals, their relative faster maturity and reproductive cycle will compensate. In all probability losses due to increased incidence of disease from a disorganized society are apt to be a much greater immediate hazard to survival than the latent effects of irradiation.

TOTAL BODY IRRADIATION

In 1912, Regaud et al. wrote about the effect of ionizing radiation on the intestinal mucosa of the dog. Since that time many domestic animals have served the investigator in his quest for knowledge concerning the biologic effects of radiation. It is enigmatic that massive doses of radiation are required to produce observable chemical changes and yet relatively small amounts of radiation kill. If the total exposure is accomplished in less than 24 hours, between 300 to 600 r usually destroys about 50% of mammals. The midlethal dose for common species of livestock at 30 days ($LD_{50/30}$) may be found in Table I. Some species seem to be more radiosensitive than others. However, considerable variations in lethal response are found in families or even among individuals of the same species (Kohn and Kallman, 1956a). Vegetative forms such as bacteria are more radio-resistant than mammalian. Physical as well as biologic variations make comparisons of results from different laboratories difficult.

TABLE I
MIDLETHAL DOSES OF IONIZING RADIATION

Species	$LD_{50/30}$(r)*	Radiation≠	References
Dog	228-252	X-ray midline dose	Bond et al. (1956)
	265-312	X-ray air dose	Bond et al. (1956)
	335-530	X-ray, 21-500 r/hr	Casarett (1950)
	335	Co^{60} midline dose	Shively et al. (1956)
Rabbit	767	250 kvp	Grahn et al. (1956)
	1633	80 kvp	Grahn et al. (1956)
	1094	Co^{60}	Rust et al. (1955a)
Swine	618	Co^{60}, 50 r/hr.	Rust et al. (1954c)
Sheep	524	$Zr\text{-}Nb^{95}$	Trum (1955)
Burro	784	Co^{60}, 50 r/hr.	Rust et al. (1954a)
	651	Ta^{182}, 18-23 r/hr.	Rust et al. (1953)
	585	$Zr\text{-}Nb^{95}$, 20 r/hr.	Lane et al. (1956)
Bacteria	50,000-500,000	X or gamma	Schweigert (1954)
Parasites	25,000	X or gamma	Alicata (1951)

*LD 50/30 = The quantity of radiation in roentgens (r) that killed 50% of the test animals within 30 days after exposure.
$LD_{50/30}$ has not been determined for bacteria or parasites and the near sterilization doses quoted for them above are given only to show the relative radio-resistance of these forms.
≠Mev = Million electron volts; kvp = kilovolt potential; r/m = roentgens per minute, a dose rate. Midline dose = dose measured at the approximate physical midcenter of an animal torso. Air dose = dose measured in air at point where the approximate physical midcenter of animal would have been during irradiation.

1. Dose

The expression of dose as used is itself variable since the roentgen, by definition, is an expression of quantity of energy absorbed by air. It is used to designate "free in air dose," "midline dose," and "absorbed tissue dose" as in Table I. Regardless of these variations, the biologic effects are in relation to the expressed dose. The dose is additive with various radiations (Vogel et al., 1955) and cumulative in a certain sense in so far as effects of previously received irradiations have a demonstrable effect upon the response to subsequent irradiations. The $LD_{50/30}$ for rats was reduced by 60% when re-exposures were made at 60 days (Hursh et al., 1955).

2. Intensity

In man, it has been found that radiation of low intensity has little recognizable effect on the skin which has been explained as meaning that the lesions are being repaired as fast as they are produced. However, with radiations of moderate intensity at least, the effect is proportional to the dose.

TABLE II
LETHAL EFFECTS OF WHOLE BODY RADIATION OF DOGS

Rate (r/hr.)	$LD_{50/30}$ (r)
456.6	335
160.0	430
21 to 25	530

3. Dose Rate

Henshaw et al. (1947) reported a reduction of lethality by 70% of a given dose when the exposure time (dose rate) was increased tenfold. The amount of radiation to elicit a cutaneous reaction in man was doubled when doses were lengthened thirty times (McKee et al., 1943). Casarett (1950) found that the $LD_{50/30}$ for dogs at various roentgens per hour varied considerably (Table II). Mice exposed to similar doses in 90 minutes and in 24 hours from Co^{60} had an $LD_{50/30}$ of 930 r in one case and 1325 r in the latter (Vogel et al., 1956).

4. Fractionation of Dose

Fractionated doses or the continuous administration of radiation may differ in their effectiveness. However, if the fractionation is not great the difference may be insignificant. It may be possible to measure these differences but it is difficult to explain them.

Hursh et al. (1955) exposed rats to acute and fractionated exposures and found that a 600 r acute dose reduced the life span by 19%. When the dose was given in 10 daily doses of 60 r each, the life span was reduced 5.8% whereas there was no significant reduction in the life span of rats given 600 r in increments of 20 r a day. Kaplan and Brown (1952) reported that the fractionation and periodicity of exposure of black mice to radiation extended survival times and decreased the lethality of specific doses. Ellinger and Barnett (1950) demonstrated the effect of dose fractionation on mice. Brues and Rietz (1948)

reported that chickens given 1000 r at a rate of 43 r/minute had 100% mortality in 14 days. However, if the dose was given in two equal exposures with a 40-minute interval, the mortality was reduced to 88%. Four exposures of 250 r with 20-minute intervals between them reduced the effect to 81% mortality. The burro has been given fractionated doses of whole body radiation until death (Table III) (Trum et al., 1953; Rust et al., 1954a, 1955b; Haley et al., 1955).

TABLE III
LETHAL DOSE FRACTIONATED TOTAL BODY IRRADIATION OF BURRO (Co^{60})

Dose/day	Survival time (days)	Mean lethal dose (r)
400	8.3 ± 1.4	3320
200	14.1 ± 3.3	2820
100	23.3 ± 1.0	2330
50	30.2 ± 3.3	1510
25	63.0 ± 13.2	1575

TABLE IV
MEAN SURVIVAL TIME FOR ANIMALS EXPOSED TO DAILY DOSES OF IONIZING RADIATIONS

		Mean Survival (days)	
Daily dose	Burro	Rat	Guinea pig
90-100 r	23.3	48.4	20.2
20-30 r	63.0	332.6	68.8

Swine have been given fractionated doses of 50 r/day until death (Trum, 1956) and accumulated a mean lethal dose several times greater than the burro. Thus we find that one domestic animal that seems to be more resistant (burro, $LD_{50/30}$, 784) than another (swine, $LD_{50/30}$, 200-400 r) and the burro, although quite different in their response to acute whole body irradiation, have a similar response to the fractionated doses (Table IV) while the rat is quite different than either.

When continuously irradiated a dose of 140,000 r caused death of mice within 20 minutes (Henshaw et al., 1946). However, after massive doses of 3500 and 14,000 r all mice lived 4 to 5 days. Burros, sheep, and cows lived in a constant flux of Co^{60} gamma radiation (40-50 r/hour) for 90 to 120 hours before total physical collapse (Trum and Rust, 1952; Wasserman and Trum, 1955).

5. Quality of Radiation

The quality of the radiation is a factor in biologic effects. By quality, we mean the type and energy of radiation or, in the case of X-rays, the characteristic spectral energy distribution. Arbitrarily, we will speak of low-energy X-rays as those under 140 Kev, relatively high-energy X-rays as those between 140-250 Kev, high-energy X-rays as those between 250 and 3000 Kev. All gamma

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energies of nuclides used in whole body radiation studies have been in the high-energy range.

Generally, the term quality refers to the penetrating power of the radiation which is directly related to energy. However, biologic effects are caused, as mentioned previously, by energy transfer or total absorbed dose. This depends not only on the quality of radiation as the initial energy of photon, but also the degradation of photons and geometry and tissue characteristics of the animal target. Cronkite and Bond (1956) have emphasized the importance of depth dose and dose distribution studies in large animal experiments, stating that the effectiveness drops off at the point that the distribution of the dose departs from uniformity whether due to energy of the photon or unfavorable geometry of the target.

6. Relative Biological Effectiveness (RBE)

The inverse ratio of the doses required of different radiations to produce a standard amount of given biologic effect is the relative biological effectiveness (RBE) of the radiations. The difference in properties of radiation can only be determined properly when the physical measurements throughout the target are accurately known - a most difficult task. RBE is often used to express differences measured by "biological dosimeters" and "air dose" comparisons. It will be recognized at once that the RBE for various radiations will be greatly influenced by the "end point" observed. The lethality of a radiation is perhaps the most common reference, however, carcinogenesis, cataract formation, and erythema are other biologic phenomena which have been used as "end points."

Evidence of experimental biologic effectiveness of various radiations has been offered by many. Boche and Bishop (1946) reported that the $LD_{50/30}$ for dogs exposed to 250 kvp X-radiation was 300 r and when exposed to 1000 kvp X-ray it was 335 r. They concluded that the relative biologic effectiveness of the 1000 kvp beam was 0.81. On the other hand, Bond et al. (1956) found no significant difference in the lethal response of dogs when midline doses from 250, 1000 and 2000 kvp X-rays were compared, the $LD_{50/30}$s being 252, 255, and 268, respectively. Shively et al. (1956) found the midline tissue dose for $LD_{50/30}$ of dogs exposed to Co^{60} gamma radiation to be 335 r. Since this is significantly higher than reported $LD_{50/30}$ midline doses for dogs exposed to X-rays under similar conditions, they concluded that the RBE of Co^{60} was 0.75 of the 250 kvp. Upton et al. (1956) found similar figures when Co^{60} gamma rays and X-rays were compared in their effect on mice. Kohn and Kallman (1956b) found the RBE of the 1000 kvp and 250 kvp X-ray in mice to be 0.839. Fuller et al. (1955), comparing the effect of 18 Mev electrons and 400 kvp X-rays on rats, concluded that the 400 kvp was 30% more lethal in the LD_{50} range. We suspect that the $LD_{50/30}$ for swine exposed to Co^{60} gamma radiations (618 r) indicates the greater biologic effectiveness of the 1000 and 2000 kvp X-radiation shown by Tullis et al. (1952) to have caused an $LD_{50/30}$ of 350-510 r. The difference in dose rates and depth dose were considered and may explain some of the observed differences.

TABLE V
COMPARATIVE LETHALITY OF AIR AND TISSUE DOSES OF DIFFERENT ENERGY RADIATION IN ANIMALS

	LD_{50} Rabbits		LD_{50} Mice	
Energy (kvp)	Air dose	Tissue dose	Air dose	Tissue dose
250	805	767	634	590
100	1332	1022	663	617
80	2525	1633	810	727

The studies cited generally indicate a decrease in RBE as the energy of the radiation increases. However, the results of Bond et al. (1956) cannot be disregarded nor can we ignore the limitations of this generalization. Grahn et al. (1956) have pointed out that the implication of nonuniformity of depth dose accounting for variations in the RBE of X-rays has not been well established. Variations in LD_{50} of mice were found with different energies in which very little difference was noted in depth dose (Table V). In both species cited in Table V, the higher energies were most effective biologically.

Burros were exposed to gamma radiation from 3 radionuclides, each with a different mean energy (Lane et al., 1956, Rust et al., 1953, 1954c). The results, given in Table VI, show a variation in $LD_{50/30}$. Since the slower dose rate or the lesser depth dose of diminishing energies should have reversed the results we may assume that a more important factor was involved. If it were a physical factor, then we may assume it to be a function of linear energy transfer (LET).

TABLE VI
LETHAL RESPONSE OF BURROS TO NUCLEAR RADIATIONS

Source	Mean energy	Lethal dose (95% confidence)	Rate (r/hr.)
Co^{60}	1.25	784(753-847)	50
Ta^{182}	1.20-0.18	651(621-683)	18-23
$Zr^{95}-Nb^{95}$	0.74	585(530-627)	19-20

To recapitulate, the physical factors of type and quality or radiations, dose, dose rate, dose fractionation, and relative biological effectiveness determine the response of the mammal to radiation. In addition to these factors, there are physiologic factors that must be taken into consideration.

7. Physiologic Factors

The body size of the animal seems to have very little to do with the response to ionizing radiation, as a perusal of the $LD_{50/30}$ (Table I) will indicate. The metabolic rate of species has little to do with radio-resistance although both of these factors may have slight bearing on survival of individuals. Sex differences in radiosensitivity have not been consistently demonstrated in the larger domestic animals. Mice under 15 days old survive longer than 30-day-old mice when irradiated but animals over 30 days old become increasingly more radioresistant. Mice from 45 days to a year old show little difference in response to radiation (Abrams, 1951; Furth and Furth, 1936; Quastler, 1945; Zirkle et al., 1946). Results of Hursh and Casarett (1955) indicate that perhaps the middle-age group is the more radioresistant, for older rats have a lower $LD_{50/30}$ than mature young rats.

When it was found that swine may survive several times as long as burros while receiving the identical daily dose of gamma radiation (Trum, 1956), it was assumed by some that the fat of the swine protected in some manner. Spiers (1946) reports that because of the low effective atomic number of fat, it can account for a small difference in sensitivity. In the case of the swine, however, the acute radiation studies indicated they were more radiosensitive than the burro (Rust et al., 1954c); thus the fat was not a factor involved.

Hibernation has an effect upon the latent response to irradiation. The effect is not clear cut. Some marmots lived longer when irradiated during hibernation than controls which were not hibernating. However, even hibernating animals irradiated with 650 to 800 r died within 14 days with characteristic blood changes (Smith and Grenan, 1951).

8. Biochemical Changes

Only a few of the biochemical changes will be mentioned to show the possible ramifications. The effects on pure or simplified systems, for example, are not to be discussed. An understanding of the biochemistry of the irradiation injury is the best hope for a rational and effective approach for the alleviation of the radiation injuries. So far, with some few exceptions, these hopes have not been realized. The studies made with the changes in enzymes and enzyme systems should hold considerable promise but to date little has been accomplished. Feinstein (1956) has expressed the opinion that, with rare exceptions, increases and decreases in enzyme activity in irradiated animals are artifacts. It must be emphasized, however, that any biochemical alteration must, in the final analysis, be associated with changes in enzymes, coenzymes, substrate, or habitat. Therefore, the efforts in this field must continue in spite of the present lack of success.

It is only the in vivo studies which clearly point out that there are enzyme system disturbances following irradiation. For example, in spite of an apparent radioresistance the functioning of the liver in carbohydrate metabolism is quickly altered. In a series of papers Lourau-Pitres and Lartigue (Lourau and Lartigue, 1950a, 1950b, 1951a, 1951b, 1952; Lourau-Pitres, 1955) show that, shortly after total body irradiation, there is a striking elevation of blood glucose. This is eventually corrected by glycogenesis and not by loss via the urine ro by catabolism. Irradiation did not alter the laydown of glucose as glycogen but there

was a striking increase in the incorporation of 3-carbon carbohydrates and other fragments such as pyruvic acid into glycogen (Rust 1956). Kats and Hasterlik (1955) have noted, in accidentally irradiated men, that there is an increase in the amino acid level of the blood and urine which many think is associated with protein degradation. Whatever the cause, there is made available by deamination a host of short-chained carbohydrates which can serve as precursors for glycogen. Lane et al. (1955) have measured a 2-fold increse in blood pyruvete in irradiated animals which may be associate with this process.

9. Radiation Syndrome

The syndrome of radiation sickness in large animals has been reviewed (Trum, 1953a). Prosser and associates (1947) have pointed out thet there is no single clinical reaction specific for irradiation damage. Many of the effects can be duplicated by other toxic agents. However, the clinical response to single or daily doses of external irradiation or acute internal whole body irradiation forms petterns of a similar course of observable signs. In general, these are: early shock-like deaths, anorexia, cachexia, electrolytic imbalance, capillary fragility, and subsequent effects such as increased loss of injected chemicals or dyes and characteristic hematologic changes which are to be described separately. Other changes are dehydration or fluid imbalance within tissue spaces, fall in blood pressure, increased catabolism, and such changes indicative of tissue breakdown as may be further reflected in weight loss and death or eventual reparation and recovery. Finally, a complex of chronic irradiation affects occurs, which is commonly referred to as "premature aging."

The acute radiation syndrome in dogs (Prosser et al., 1947) and the observations of Cronkite (1949) on goats exposed to radiations of an atomic detonation at Bikini, have significantly contributed to our knowledge of the irradiation syndrome in domestic animals. The burro, however, is the only large domestic animal experimentally exposed to ionizing radiations in large numbers. Since the response of cattle, sheep, and swine exposed in a similar manner closely resembles that of the burro, the latter may serve as an example of the total body irradiation effect in domestic animals.

For the first few postirradiation days, the burros appeared to be in good health. Then followed a four-or five-day period of apathy. Increased irritability and hyperesthesia, decreased food and water consumption, and a few deaths occured. For the next week or so, there appeared to be recovery, some animals appearing euphoric but ultimately there occured a period of apathy and inappetence accompanied by severe weight loss.

Animals surviving near lethal doses bled from small wounds or venipunctures or oozed bloody serum from mucous surfaces after the second week. Edema of head and throat was observed and shortly thereafter a second wave of deaths occured.

Vomiting, not a physiologic function of the burro, occurs post-irradiation in swine and dogs (Brecher and Cronkite, 1951; Gleiser, 1953a).

Rhinitis and bloody diarrhea, although seen in small laboratory animals and dogs, goats, and swine, was not seen in burros after irradiation.

Gross gingival ulcers in burros and dogs make an offensive malodorous mouth in the radiation sick of these species (Trum, 1953a; Gleiser, 1953a). No coat loss was seen due to experimental gamma irradiation. Goats, however, had loss of hair when exposed to radiations at the Bikini detonation in 1946 (Cronkite, 1949, 1950). Van Dyke and Huff (1945) reported that epilation occured in a nonirradiated member of a parabiotically united pair of rats. This seemed to indicate tha presence of a circulatory factor.

Special areas of the burro's hide, a small differentiated patch of skin above the external tarsus and the skin of the forearm, seemed to itch after irradiation. A few burros had licked or scratched these spots until large sores were created (Trum et al., 1952).

Early eye lesions consisted of conjunctivitis, keratitis, corneal ulcers, nebula, leukoma, and corneal vascularization. This complex should not be confused with delayed lenticular opacities following X or gamma radiation. The eyes of animals with conjunctivitis wept copiously and the conjunctiva became edematous, particularly in swine, and ectropion occured. These lesions of the eye are caused by ionizing radiations. Byrnes (1955) reported the occurence of chorioretinal pathologic changes in rabbits exposed to the flash of atomic detonations as far as 40 miles away. In this case, the damage was not caused by ionizing radiation.

Burros and swine have had neuromuscular spasms following irradiation even in median lethal ranges. Twitching of facial muscles and spasmodic retraction of tha lips were occasionally seen within 48 hours after exposure. The condition known as "stringhalt" in which the hocks act in an exaggeratad jerky movement is often seen. Hopelessly sick burros pop joints and quiver muscles while standing and bob their heads up and down in jerky motions. These observations are not commonly reported as happening in other experimentally irradiated animals however. Langham et al. (1956) reports coarse, jerking movements appearing in animals exposed to massive doses of radiation three or four days after exposure.

Although this sign was not reported in other irradiated mammals, the burro may react to whole body radiation exposures in the range 500 to 1000 r similarly to the horse with encephalitis. Incoordinate walking, circling, and pressing against walls with the head are some of these signs. The sign does not indicate ensuing death, since some affected animals have recovered. The micropathologic changes of the brains of fatal cases did not suggest that an infective agent was involved.

Lameness, seen to some degree in all species of animals irradiated on the UT-AEC exposure field at Oak Ridge, Tennessee, is not well understood. It appears early in the irradiation syndrome, is a function of weight support and not a performance type, a sort of leg weariness which is transient.

Another clinical observation of interest was the observance of an irradiated hog after a large (10 $cm.^2$) area of skin and flesh had sloughed frum

its hock. Although the surrounding tissue was nacrotic, the ligaments eroded and the bones became clearly visible; there was no redness, swelling, pus or pain. The animal walked with very little dysfunction of the open joint. We have been told that dogs, whose bones have fractured due to irradiation from internal radiation, (Dougherty, 1956) have been observed to show no pain and may try to walk on the fracture if not restrained.

The signs of whole body radiation sickness observed in an animal depend on the radiation dose, rate of administration, and survival time. All or none of the signs enumerated may occur in any one case. Similarly, the mode of death is variable. In all groups of experimental animals, there have been waves of mortality. Certain significance has been attached to these waves.

Between the most massive of radiation exposures and death, there is a latent period. It may be a matter of minutes after kiloroentgen exposures (Langham et al., 1956) or a matter of years (Trum, 1956).

A shock-like reaction and death follow supralethal doses of radiation within a few days. When deaths occur after the third day they are usually attributed to severe intestinal damage. Regaud et al. (1912) reported the death of a dog in one day postirradiation and described severe intestinal histopathologic changes. Quastler et al. (1951) described the acute intestinal weights were reduced by 15 to 35% during the first few days after irradiation but returned to normal within a few days. Gleiser (1954a) described gut recovery in serially sacrificed dogs following irradiation. After the peracute deaths, there was a period during which animals appeared nearly normal, which was followed by a wave of deaths generally considered to be caused by septicemia or hemorrhage. All animals destined to die of the acute radiation syndrome died within 30 days with few exceptions. Low lethal doses or extended irradiation time may stretch out this mode of death for several weeks.

Unlike the smaller experimental animals, some burros died very suddenly within a few days of an exposure not considered to be massive, in fact not 100% lethal (Rust et al., 1954c). The deaths, therefore do not meet the criteria of intestinal death as outlined by Quastler et al. (1951), nor are the doses sufficiently high to suspect the neuropathic deaths described by Langham et al. (1956).

Other animals survivors of doses as low as 25 r/week for 14 weeks, died after 3 to 5 years with a record of progressive leukopenia and thrombocytopenia. Clinically, they were normal appearing animals until the time of their deaths (Trum, 1956).

10. Hematology of Radiation

The hematologic effect of ionizing radiation has been reviewed by Jacobson (1954). It had been recognized for years that the blood-forming tissues are among the most radiosensitive. The effects may be summarized as a dose-dependent reduction in lymphocytes, thrombocytes, polymorphonuclear leukocytes, and erythrocytes, as well as a clotting defect resulting in petechiosis or hemorrhage.

The hemorrhagic syndrome of goats and swine after atomic bomb exposure was considered to be predominantly a result of a combination of increased vascular fragility and thrombocytopenia (Cronkite, 1950). The clotting defects were infrequent and the causes inadequately explained. Subsequent experimentation indicated that the loss of thrombocytes resulted in the clotting defect (Jackson et al., 1952a). Concurrent with a reduction in platelets and typical pancytopenia in postirradiated dogs was a loss of prothrombin utlization (Jackson et al., 1952b).

The cytologic changes in the blood of irradiated burros have been summarized as follows (Rust et al., 1954b): Erythrocytes were reduced in burros following total body exposure to gamma radiation. Hematocrit and hemoglobin values followed the same pattern of response as the red blood cells. An increased erythropoiesis, demonstrated in bone marrow from the 10th to 20th postirradiation days, was soon reflected by an increase in the peripheral blood of burros, significantly increased in the marrow from the 5th to 10th week.

Changes in the white blood cells were principally a reduction in lymphocytes during the first two weeks. The minor reduction in neutrophiles was greatest about three weeks after exposure to the radiation. It was observed that animals failing to check a fall in neutrophiles at this time died whereas others made gradual recovery. Monocytes were reduced. There was an absolute eosinopenia but a relative eosinophilia. Sedimentation rate increased linearly with decrease of red blood cells, suggesting little change in the plasma proteins in the irradiated burro.

There was a retardation of whole blood clotting time, a clotting defect in recalcified oxalated plasmas, a lessening of clot retraction, and pronounced diminution of prothrombin utilization rate (Trum and Rust, 1953).

The clotting defect in burros was expressed in nearly direct relation to decrease in circulating thrombocytes. However, the defect was apparent with less than 20% reduction in platelets. Recovery occured while platelets were less than 50% normal.

The effects of whole body irradiation have been observed upon the blood cells of rabbits within 15 minutes. The effect, a reduction in lymphocytes, was not great below doses of 25 r and there was a return to normal within 24 to 48 hours. However, in the LD_{50} range, the recovery of lymphocytes is the last to be noted in the hematopoietic system along with the platelets. In fact, burros having received doses from 350 to 530 r (air doses which were not acutely lethal) had not fully recovered normal blood counts two years after irradiation (Trum, 1956).

Red blood cell counts were normal within a few weeks following irradiation in some animals. Several earlier workers have indicated a stimulating effect on hematopoietic tissue due to whole body radiation. Although there has been a compensatory rise noted in cytometry between the 4th to 10th postirradiation day in many experiments, this has always been preceded by a reduction. Some (Ross et al., 1952) have explained the compensatory rise in erythrocytes as a phase of hemoconcentration.

Whereas severe anemias have been reported in small laboratory animals, postirradiation anemias of large animals when judged by severe changes encountered in common diseases of domestic animals, such as microfilariasis, anaplasmosis, or infectious anemia, are not critical in the irradiation syndrome. Reductions of more than 50% erythrocytes are unusual.

Although capillary fragility was detected in all irradiated animals, tht flooding of lymphatics with red blood cells was never so extensive in the burro as in the hog or other animals. The simultaneous loss of fluida as well as red blood cells has resulted in a masking of individual hematopoietic effects (Ross et al., 1952).

Death attributable to frank hemorrhage in large animals was rare and usually attributed to a traumatic injury or organ capsule rupture. Clotting, although delayed, is not otherwise affected within the tissue of intact animals as in the test tube due to adjacent tissue factors. However, clot retraction is improved little, if any, by these tissue factors.

In summary, the characteristic blood picture of the irradiation syndrome in large animals may be:

(a) An immediate decrease in numbers of circulating lymphocytes with a slow recovery rate if doses are near lethal range.

(b) A lesser and slower reduction and faster recovery of polymorphonuclear leukocytes and erythrocytes.

(c) A clotting defect related to a thrombocytopenia and characterized by a slower clotting time and impaired clot retraction which appears about two weeks after exposure and usually repairs quickly; however, relapses have been encountered.

(d) The peripheral blood changes reflect changes more quickly than the lymphopoietic system whereas morphologically the erythropoietic system reflects a radiosensitivity and prompt recovery.

(e) The evidence for the existance of radiation "stimulation" of hematopoiesis is weak.

11. Pathology of Radiation

In keeping with the general concept of this presentation, no detailed review or description of the pathology of radiation will be attempted but general facts or specific differences will be cited.

Warren (1942) reviewed the histopathology of radiation injury and it has again been summarized by Bloom (1954). Tullis et al. (1954, 1955) described the lesions of whole body irradiation in swine. Gleiser (1954a) reviewed the concepts of pathogenesis of acute radiation sickness in the dog and had earlier described the histopathologic effects in detail(Gleiser 1953a, 1953b, and 1954b).

Tullis and Warren (1947) described the gross autopsy observations in animals exposed at Bikini as being: gross hemorrhage with blood clots in pelvis of tha kidney in goats and pigs; lymph glands enlarged and hemorrhagic; brain and meninges retentive; purpura of skin sometimes seen; the lungs

drippad a blood-stained fluid and had dark patches resembling hemorrhage in lobar pneumonia; consolidation was seldom seen; the gastrointestinal tract had acute ulcerations, never deeper than the submucosa, if death occured in 3 ro 4 days. Liver, spleen, and adrenals were normal.

The pathologic changes reported will vary greatly from experiment to experiment. The conditions affecting survival and the clinical syndrome also affect the pathologic picture. For instance, an animal must live sufficiently long for blood dyscrasias to appear. Species like the burro do not pour young erythrocytic cells into the circulation as other species might. Their lymph and spinal fluid are relatively clear at stages of the irradiation syndrome when that of swine is apt to be well mixed with blood. Animals that die rapidly following irradiation show either none or very few gross pathologic changes.

All of the laterations reported by Tullis and Warren (1947) have been observed in large animals experimentally exposed to whole body gamma radiation. Additionally other changes were seen.

Frank hemorrhages occured when organ capsules were ruptured by trauma of handling, migration of internal parasites, fighting, or normal physiologic functions like ovulation. Large perivalvular ecchymoses of the heart and hemorrhages about the Purkinje fibers were observed.

The stomach of animals dying of radiation sickness is usually filled either with ingestia or fluid. The pyloric sphincter is abnormally tight and will not permit emptying without considerable pressure.

Under certain conditions, epiphysial breaks are caused by manipulations that would not induce fractures under normal circumstances. Arthritis, although commonly seen in swine following irradiation, is seldom seen in sheep or burros.

Spontaneous ulcers of skin occured in some swine which were irradiated repeatedly. Only after a traumatic wound, sometimes self-inflicted by biting or licking, were ulcers of the skin in burros observed with the exception of those found commonly on the face, muzzle, or forehead.

Wounds, contrary to expectation, never appeared serious per se, although the healing process in radiated animals is not well understood. No pus was observed to accumulate in wounds that would ordinary become suppurative under the conditions in which the animals live. The wounds on survivors heal slowly but without other complications.

No epilation was observed in the experimental irradiation syndrome but occasionally the hair would strip very easily from hogs that died of irradiation sickness. Twenty or more hogs receiving a minimum of 500 r were slaughtered the following day with controls. The hair on the irradiated hogs did not have to be scraped off after scalding as on the nonirradiated but could be removed by hand wiping. No investigation or explanation of this phenomena was attempted.

The focal irradiation of the skin will be dealt with in the discussion of beta burns. However, in some animals, total body irradiation with 400 to 500 r of X-radiations may cause damage to hair follicles with epilation possible in about three weeks. This effect may be permanent or temporary. The glands of the skin have a specific sensitivity to ionizing radiation with hair follicles, sebaceous glands, and sweat glands being affected in that order.

The histopathologic changes leading to these effects are briefly: degenerative changes of reversible or irreversible nature; inhibition of mitosis or abnormal mitotic figures. It is perhaps impossible to use the observed death of the cell as a criterion of damage. Occasionally, mitosis ceased within one-half hour after total body irradiation and recovered within 12 hours. Even then, not all cells of all tissues respond alike (Warren, 1942). Doses that affect epithelial and connective tissues may have little effect on nerve and muscle. Lymph nodes are extremely sensitive to total body irradiation and respond with the death of lymphocytes and reduction in size of organ.

Bone, histologically a connective tissue, responds by showing hypertrophy of cartilaginous cells, loss of normal interdigitation of cartilage in spongy bone, and arrest of growth. The latter effect may be of serious consequences in radiation therapy of growing bones.

Although the changes in the reproductive system are taken up elsewhere, it may be well to mention here that the response to radiation is rapid and dramatic. Brennan et al. (1954) have used measurement of testicular atrophy radiobiometrically and refer to other similar studies. Eight hours after exposure, intact spermatocytes may be found but spermatogonia will have died. At 21 days, only spermia dn Sertoli cells were found and shortly thereafter only Sertoli cells. Recovery of the testis usually began by the second postirradiation month.

Irradiation of the ovary leads to atrophy and sterility. Formed corpora lutea are not affected by doses damaging to the ovary. The presence of the hemorrhagic phase at time of ovulation may interfere indirectly with the function of the corpus luteum (Trum et al., 1952). Supralethal doses of 2000 r or more of whole body irradiation are necessary to affect the ovary grossly and permanently.

Gleiser (1954a) has demonstrated by examination of serially sacrificed dogs the rapid destruction of the intestinal epithelium and a remarkable recovery even in animals which were certain to die from irradiation injury if they had not been sacrificed. The visible microscopic changes that appear are: degenerative changes in nuclei, pyknosis, scattering of nuclear material, necrosis of cells, bizarre mitotic figures, or cessation of mitosis.

The epithalia of the cornea and conjunctiva are quite sensitive to irradiation. Regeneration of normal tissue is delayed. Severe conjunctivitis and leukomas were observed in irradiated burros (Trum, 1953b). As already stated Byrnes (1955) saw coagulation necrosis in the retina of rabbits placed up to 40 miles from an atomic detonation. This was attributed to nonionizing radiations, however. Beta particles, X and gamma rays, as

well as neutrons, cause the formation of cataracts in animals after variable latent periods. The morphology, pathogenesis, and species specificity as well as RBE of radiations have been the subject of several conferences (National Research Council, 1954).

Minor changes have been reported in other organs. The adrenals are relatively radioresistant but have shown latent effects. A loss of tissue in the zona glomerulosa after chronic total body irradiation has been observed in burros. Lane et al. (1954) reported a reduction of gonadotropin following total body irradiation of rabbits.

Korson and Botkin (1953) have reported on the histopathologic changes of the rat pituitary following total body irradiation. The changes were closely related to the functional alterations. For instance, a marked increase in acidophiles concurrent with a disease of chromophobic cells suggests that the adrenocorticotropic hormone increases in radiation injury.

Histopathologic changes in the thyroid gland have not been observed following total body irradiation but the destruction of the gland may be brought about by large local doses (Marks et al., 1955). However, physiologic changes due to total body irradiation have been seen (Monroe et al., 1954; Schoolar et al., 1954; Rust, 1956) as well as a hyperplastic irradiation response.

Lushbaugh (Langham et al., 1956) observed a typical pathologic picture of acute radiation damage in a rat after two hours' exposure to massive doses of gamma radiation. Increasing the dose could neither produce a more intense nor quicker reaction. This, of course, is very meaningful when the effect of ionizing radiation is estimated per se or by abscopal reactions. Many have claimed that animals do not die of the direct cellular damage but from the "alarm syndrome" (Betz and Fruhling, 1950). To say the least, the complex nonspecific neuroendocrine reaction which Selye (1950) calls the general adaptation syndrome complicates the physio-pathologic as well as the biochemical study of animals exposed to ionizing radiation. In order to conform to this "reaction d'alarme" or "stress," there should be an increased production of adrenocorticotropic hormone while prolactin, gonadotropin, and growth-stimulating hormones should be inhibited. Some changes such as these have been seen.

In summary, it seems that there is no specific gross or histopathologic picture of radiation death. Within certain dose limitations, however, it is often possible to diagnose radiation injury by a summation of changes and a consideration of the relative tissue sensitivities.

12. Carcinogenic Effect of Radiation

Before proceeding to details of the carcinogenic effects of radiation, it might be well to summarize the effects of ionizing radiations on man instead of animals. Since statistics on veterinarians are not available, the fate of the physician will be followed. Warren (1956) reports that the

radiologist has a 5.1 years shorter life expectancy than the population average after passing the 25th year.

This is but one of several such reports. March (1950) reported 14 leukemic deaths out of 299 deaths in radiologists whereas there were 344 leukemic deaths out of 65,992 physicians who were not radiologists. Peller and Pick (1951) have given the per cent leukemias in malignant deaths among physicians in consecutive 5 year age groups between 25 to 44 years of age as 70, 33.3, 22.3, and 22.6% in contrast to the 14.4, 15.8, 7.9 and similar although the rates are lower for physicians and nonphysicians between 45 and 85 years of age. Dublin and Spiegelman (1947) found leukemia 1.75 times more often among physicians; at the same time, there was a lower death rate from cancer of other types in physicians than in the general male population. A tabulated statistical review on the subject has been prepared by Ingram (1956). Fractionated radiation doses produced greater carcinogenic effects (Lamson et al., 1956).

Furth and Furth (1936) first reported the occurrance of neoplastic diseases in mice following X-radiation. Henshaw (1944) produced leukemia in mice with X-rays, and Upton and Furth (1953, 1955) reported spontaneous pituitary adenomas in mice following exposure to ionizing radiation. In analyzing these reports, it might be added that ionizing radiation increased the incidence of the types of tumors spontaneously produced in the species. It was found that leukemia could be induced in guinea pigs by gamma radiation at 8.8 r/day (Lorenz and Congdon, 1955). Following radiation some chemo-protective agents tried have been responsible directly or indirectly for an increased incidence of neoplasms in experimental animals (Brecher et al., 1953; Mewissen and Brucer, 1957). Brues et al. (1949) give the comparative carcinogenic effect of X-radiation and radiophosphorus. They report that 400 r of total body irradiation is a more effective carcinogen when exposures are made at 40 r a day for 10 days than when given in one dose. However, the carcinogenic effect of radiophosphorus was similar whether given in one dose or fractionated over 10 days.

A hog, subjected to daily exposures of 50 r/day gamma radiation developed lymphatic leukemia and died on the 199th day. It was one of 56 treated hogs and the only one to develop leukemia (Trum and Carll, 1957).

The incidence of leukemia rose in Japan following the nuclear detonations but unlike the types found in most experimental animals, it was of a myeloid or mononuclear variety (Bugher, 1952).

Although writing of the effects of total body irradiation at this time, rather than reintroducing the subject of carcinogenesis and radiation later, we will mention tumors caused by partial body irradiation. The earliest recorded changes due to ionizing radiations were noted in the skin of early investigators using radium or roentgen rays. Brues (1951) related that the carcinogenic effect of roentgen rays was reported as early

as 1896, only six months after the announcement of Roentgen. Friehen (1902) diagnosed the first skin cancer arising from roentgen rays. Becquerel was reportedly the first to experience a lesion from radium emanations (Colwell and Russ, 1934). He is said to have carried a sealed tube of radium salt in his vest pocket until an ulcer developed. Fortunately, he associated the two and removed the tube of radium. Healing took place subsequently. It was not until 1923 that MacNeal and Willis ascribed skin carcinomas to the long-time handling of radium tubes and applicators. Such cancers often had fatal termination following multiple or serial amputation of an appendage. Beta radiation, has been associated experimentally with tumor formation in rats and mice (Raper et al., 1951). Cattle exposed to the fallout beta radiation in 1945 on their backs have not, after 13 years, developed malignancies.

Clarke (1955) has reported on a number of cases of thyroid carcinoma arising in children at an average of 7 years following X-irradiation for suspected enlargement of the thymus, bronchitis, infected tonsils, and adenoids. The most important feature of this is the comparatively small dose to the neck region that apparently initiated cancer. Some doses as low as 250 r were recorded as being adequate. Simpson et al. (1955) studied 1400 of 1722 children who had received X-irradiation of the neck region between 1926 and 1951 and found that they had a much higher frequency of thyroid carcinoma than either their untreated brothers and sisters of the general population of equal age. These findings intensify the concern of many since such doses are possible to the operators of X-ray equipment if it is not adequately shielded.

The induction of bone tumors from externally applied roentgen irradiation has been known for many years (Lacassagne and Vinzent, 1929). The same year Martland and Humphries (1929) associated bone sarcoma with the mesothorium ingested by luminous dial painters. The latter is of considerable interest because it is from these cases and others receiving radium intravenously that the maximum permissible concentration (MPC) of bone-seeking isotope has been established. Looney et al. (1955) have reported on the chronic effects of therapeutically used radium salts in which 8 or 44 patients received various amounts of radium as much as 40 years before the development of osteogenic sarcoma. Finkel and Brues (1955) produced sarcoma of the bone in dogs following the single administration of radiostrontium. These latent effects are mentioned first because they are the most spectacular. One must not lose sight of the fact that local irradiation, whether from an external or internal source, to the epiphyseal plate can have profound affects upon the subsequent growth (Heller, 1948) and may even cause a separation of the epiphysis or pathologic fractures. Some such disturbances probably have been initiated by veterinarians using large doses of irradiation about the joints of growing animals.

13. Infection and Immunity Effected By Radiation

Hektoen (1915) first reported that irradiation of the body of mice would reduce their ability to produce antibodies. A recent review (Taliaferro and Taliaferro, 1951) concluded that small amounts of X-rays,

sometimes local exposure, occasionally enhance antibody formation and specific immunities of experimental laboratory animals to nonliving antigens and certain infections. The mechanism has not been clarified. Large amounts of X-rays have occasionally been reported to produce beneficial results such as the reduction of infectivity of trichina. Lethal doses often decrease postimmunity to specific infections and lower antibody formation. Destruction of lymphoblasts was considered a probable reason for these reactions. Other factors, however, must be considered.

Ionizing radiation reduced or abolished active or passive immunity to bacterial infections (Fulton and Mitchell, 1953a and 1953b). The response was a function of dose with significant changes occurring when the exposure was greater than 200 r.

The irradiation of rabbits, two days to several weeks previous to the administration of an antigen, completely inhibited antibody formation (Dixon and Talmage, 1955). It has been reported that total body irradiation after the antigen injection would not suppress antibody formation. Other investigators found an injury to the mechanism of immunity caused by irradiation both pre- and post-contact with antigen (Silverman and Chin, 1955). The injury was dose dependent and the closer to the time or irradiation the antigen was given, the greater the inhibition of immunity.

Immunity against tetanus toxin was completely destroyed by irradiation. Others have stated that acquired immunity to viral infections and active or passive immunity to bacterial toxins were affected little, if any, by total body irradiation adequate to decrease the immune response did not harm passively transferred immune bodies. Because the serologic determination of irradiation inhibited antibody formation does not necessarily reflect the immune state, changes may heve been missed by those employing this technique (Hale and Stoner, 1954).

There is no convincing evidence that radiation in small doses stimulated antibody production. Smith and Gump (1954) also pointed out that there was no connection between preirradiation specific antibody titer and total body irradiation sensitivity.

The transient morphologic changes due to total body irradiation such as occur in lymphoid tissue, bone marrow, and gonads, recover long before the immune system is repaired. This has been taken to indicate the disassociation of antibody formation and lymphoid tissue. In the alarm or adaptation response, there was no increase of circulatory antibodies associated with reduction of lymphocytes (Lacomte and Fischer, 1949).

Di Luzio (1955) reported that there was a reduced ability of the reticulo-endothalial system of the liver, lungs, and spleen to phagocytize a radiogold colloid after total body irradiation. Gordon et al. (1955a) have observed that the reticulo-endothelial system of the irradiated rabbit can clear the blood of bacteria for a few hours. Although observing a decrease in antibody titer related to total body irradiation with doses of 400 r and up in rabbits, when injection was made at least 6 hours postirradiation, Gaude and Coursaget (1956) found

that gamma radiation had no deleterious action on the phagocytic action of polymorphonuclear cells of the guinea pig.

The problem of immunity following irradiation cannot as yet be dismissed as settled. The suppression of bone marrow and altered activity of phagocytes within certain dose ranges are thought by some to still play an important part in survival following total body irradiation (Shechmeister, 1954). Infections unquestionable influenced survival time and lethal dose (Hammond et al., 1954a, b). However, the complete absence of infection did not prevent irradiation deaths in the germ-free animals of the Lobund Institute (Gordon et al., 1955b).

An association of postirradiation parental colonization in tissue by normal intestinal dwelling nonpathogens has been observed concurrantly with a decrease in the immune response. Allen et al. (1948) have pointed out that, in the dog at least, this was a terminal affair only. In our experiments with burros (Mayhew et al., 1955) the bacterial transgression of the gut, either in the isolated or intact burro gut, did not take place until the hemorrhagic diathesis was also present. The same organism which was used in the burro studies, Serratia marcescens, when fed to mice was found to penetrate normal mouse intestine but was contained within the mesenteric lymph nodes. After total body irradiation, the organism passed through the lymph nodes (Gordon et al., 1955b).

Ciordia and Jones (1955) reported the effect of total body irradiation on the infectivity of mice with internal parasites. The ability to calcify and thus contain infective larvae was lost. Investigators at the Argonne National Laboratories (Brues, 1956) have also reported the effect of irradiation on immunity to parasitic infection. Bustad (1956) saw the loss of the ability of sheep to encapsulate infectious caseous lymphadenitis lesions following total body irradiation.

14. Reproduction and Radiation Effects

In general, irradiation effects in reproduction are: reduction in fertility, embryologic aberrations, retarted fetal or infant development, and genetic mutations. However, there are no distinctive effects due to ionizing radiations, only incremental changes are manifest.

A reduction in female fertility may be accomplished by affecting the production, fertilization, or development of the ova. Female mice have been sterilized by 100 r of X-radiation to the ovaries (W. L. Russell, 1956). Although ovarian dysfunctions occur subsequent to radiation exposures, more than 500 r are necessary to sterilize a woman. Zavon (1956) has written that sterility resulting from radiation is largely a folk tale as it requires more radiation to cause sterility than death. Large domestic animals probably cannot be permanently sterilized by acute, sublethal doses of total body irradiation. It is possible that the reproductive life of the female might be shortened.

A group of 60 female burros, survivors of lethal dose experiments, were observed to have normal estrous cycles 4 years after exposure (300-530 r) of total body gamma radiation with Co^{60} (unpublished records, UT-AEC, ARP).

The embryo is particularly sensitive to radiation injury. Twenty-five roentgens given to pregnant mice produced quantitative litter variations and 50 r given at a critical time produced demonstrable fetal abnormalitiss (L. B. Russell, 1954). Irradiation during the period of preimplantation, 0 to 5 days in the mouse, leads to an all or none response. There is a high incidence of fetal deaths but those that survive are normal. Irradiation during the period of major organogenesis (5-13 days in a mouse) results in a high rate of prenatal or neonatal deaths and a peak of gross abnormalities. Irradiation during the late period of the fetus (13-20 days in a mouse) resulted in less grossly apparent effects at birth but caused a number of delayed effects.

A tridivisional or direct chronological comparison of gestation periods of various species is impossible. An equivalent age of the human embryo and the mouse has been approximated. The human period of preimplantation has been estimated to be about a week, the period of major organogenesis, 6 to 35 days, and the human fetal development equivalent to the unfinished mouse of 20 days is found to be about 90 days (Otis and Brent, 1952).

The specific equivalent ages of fetal development for the various domestic animals can only be approximated (Hamilton and Laing, 1946; Melton et al., 1952; Patten, 1948). The period of implantation may be extended a week or more, whereas, the period of major organogenesis will have been completed within the first third of gestation. A concept of the critical time is of real importance when evaluating radiation injury. Embryonic aberrations, such as spina bifida, could have resulted from an exposure during the period of major organogenesis butwould not have been caused by an irradiation of a formed fetus.

No embryonic aberrations were produced by the irradiation of 15 pregnant (28-45 days) Hereford cattle. The exposures might have been too soon or too late, the number of embryos exposed too few, or the dose of 300 r total body gamma radiation too low (unpublished data, UT-AEC, ARP).

Complete, permanent male sterilization apparently does not occur following sublethal doses of total body irradiation, although relatively small doses (50 r) may produce histologically recognizable changes in the germinal epithelium. Male survivors of exposures in the lethal dose range remain fertile for a few weeks, gradually become temporarily sterile and recover concurrently with an adequate repopulation of spermatogonia. The response indicates a relative sensitivity of spermatogonia and resistance for sperm, spermatids, and Sertoli cells (W. L. Russell, 1956).

Complete sterilization of the male dog was reported following 3 Haut-Einheit-Dosen (X-ray) and the results were considered to be due to an irreversible atrophy of tubular epithelium (Fontaine, 1948). When dogs were exposed to X-rays at a rate of 3.0 r/week, given 0.6 r/day X 5, there was a progressive declination of sperm after the 20 to 30th week. Marked morphologic changes and infertile matings resulted when dogs had been treated for 40 to 60 weeks and had sperm counts about 10% of those of the controls. No radiation effects were observed in dogs receiving 0.3 to 0.6 r/week for 2 to 4 years (Casarett and Hursh, 1956).

A review of the effects of ionizing radiation on fertility of mammals and an estimation of sterilizing doses has been made by Casarett (1956). Three days

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after exposure to 750 r of gamma radiation, a reduction in spermatogenesis was histologically apparent in burro testes. Survivors have a complete cessation of spermatogenesis at 30 days and histologic signs of recovery 65 days after exposure.

Preliminary studies on the semen of bulls which had been exposed to 400 r total body gamma radiation indicated a rise in abnormal types during the 6th week postirradiation, approximate aspermia (5%) at the 18th week, and recovery after the 20th week (Murphree, 1956).

Although the exposed male is fertile for a period immediately following irradiation, the possibility of producing nonviable or aberrant young may be definitely increased at this time.

The increased mutation rate caused by the irradiation of genetic material is emphasized by geneticists (Muller, 1950, 1954, 1956). Ionizing radiation may be expected to produce the types of abnormalities that would have been observed in any biometrically large population. The ratio of observed types of abnormalities due to irradiation may or may not be the same as that effected by other causes.

Mutations are the results of permanent changes in the chromosome. Results of experimentation with mice, the only available statistically significant data concerning mammalian radiation genetics, indicate that the mutation rate was affected to a greater extent than observed in Drosophila studies. Observing the occurrence of mutations at seven specific loci on mouse chromosomes, it was found that 600 r produced an increase more than 25 times that of normal and 60 r more than tripled the incidence (W. L. Russell, 1956). Species with a greater number of chromosomes may suffer even greater genetic injury.

Lethal mutations usually occur more often than other visible mutations. Lethal mutations, some of which may not be observed, may cause prenatal death. However, the majority of mutant genes usually have some degree of dominance. Genetic effects are essentially irreparable, cumulative, and self multiplying. Genetically undisturbed populations, such as found in wild life, reach an equilibrium wherein the production of mutants and the elimination of mutants are about equal. Danforth's fundamental theorem of genetic equilibrium states that the frequency with which a given mutant characteristic is present in population is equal to the frequency with which it arises by mutation, multiplied by the average number of generations during which a gene for the given characteristic has been able to manifest itself before being eliminated by reason of the disability it confers. This equilibrium is disturbed by a mutaganic environment, such as an increase in background of ionizing radiation.

However, even in human populations with reasonably good vital statistics there is a great latitude in estimates of the average spontaneous mutation rate. Spontaneous mutation rates for aberrations in a domestic animal are too unreliable to make an index. It would be impossible to detect radiation-induced mutations in offspring or even later generations unless vast numbers of clear-cut

abnormalities could be distinguished circumstantially from increases caused by other changes in mode of living such as the introduction of mutagenic antibiotics, pharmaceuticals, industrial pollution, or foods.

Zootechnically, a selective multiplication of advantageous mutants is ordinarily practiced by animal husbandrymen. A rationally directed selection of breeding stock can eliminate individuals having an excess of undesirable mutant genes. Therefore, there is little concern for a potential increase in mutation rates of domestic animals due to ionizing radiations.

In recapitulation, it may be stated that the problem of reduction of fertility in domestic animals by exposure to ionizing radiations is not serious. Acute doses, large enough to cause permanent fertility impairment, will seriously affect all animal life to a far greater extent.

Although embryonic abnormalities may be produced by exposure to ionizing radiations at a critical time in pregnancy, the amount of radiation or the critical times for exposures are known only in general for the large domestic animals. It is known that certain effects can be produced only when the exposure to radiations occurs during a critical period. For example, an exposure during the time of major organogenesis might produce a spina bifida, whereas such a monster could not be produced by irradiation during a terminal period of gestation.

Mutations due to radiation cannot be distinguished from other naturally occurring genetic changes. Vast numbers of animals would have to be observed for many generations to detect an increase in frequency of phenotypic expressions of mutations. As a matter of fact, due to the practice of selective breeding the opportunity for stock improvement should equal or exceed deleterious effects.

INTERNAL RADIATION EFFECTS

The whole body irradiation syndrome has been produced by the presence of radionuclides within the body. The radiobiologic effects are changed only by the proximity to the source and the absorption of energies from molecules that are themselves part of the cell or tissue fluids such as radioisotopes of carbon, hydrogen, or sodium.

The effect will still be dependent upon the energy transfer and the subsequent complex reactions. A radionuclide, such as Na^{24}, with an energetic gamma radiation, diffused as an electrolyte of the blood and tissues has been quite effective in producing a total body irradiation syndrome (Dale et al., 1943; Jacobson and Simmons, 1946). Ferguson et al. (1952) produced acute irradiation sickness in dogs internally irradiated by radiogold.

A pseudo-whole body irradiation syndrome was seen in sheep given radium and radiostrontium internally by Kuhn (1955). Because of the intense local irradiation caused by the large doses of radium (5-25 uc./kg.) and radiostrontium (50 uc./kg. retained dose) bone marrow and circulating blood cells were destroyed resulting in a syndrome similar to total body irradiation.

Isotopes formed by the fission of uranium and plutonium are being spread over land and sea. Libby (1956) and Eisenbud (1956) have described the present level of distribution. We may deduct: (a) that the present level of radioactivity from fission products is not an immediate health hazard, and (b) that the widest path of entry into human beings of fission products is through animal products, particularly milk.

The radionuclides of alkaline earths, calcium, strontium, barium, and rádium, are of special interest in the biologic cycle. All are interchangeable in bone metabolism with a specific order of preferences for each element. Bauer et al. (1956) have shown that there is a marked preference in the excretion of barium and calcium by both the fecal and urinary route. This would be one method of preferential action by which the barium accretion in the skeleton would be reduced. Harrison et al. (1956) estimated the Ca, Sr, Ba ratio of intestinal absorption of available metal in man to be 10:5:1.

Comar and Wasserman (1956) have recently reviewed the relation of strontium to calcium metabolism in domestic animals and man. Lapp (1956) has theoretically discussed the limits of radiostrontium in peace and war.

The rare earths are represented by a number of fission products. To date, however, radiocesium seems to be the only one of possible importance. Miller and Marinelli (1956) reported that an energy peak corresponding to cesium-137 was found in a number of human subjects examined by a large scintillation counter. Further study of possible sources implicated meat and milk. They suggest that radiocesium is gaining access to the human body by way of grazing animals, i.e., the milk and meat animals. Here again the problem comes into the range of veterinary medicine. Little is known about the toxicity of radiocesium. Hood and Comar (1953) give the distribution of radiostrontium are of osteogenic origin which might have been expected from the location of the strontium molecule within the bone structure and from the report of Martland and Humphries (1929).

A report of radionuclides in the agricultural food chains was read by the Atomic Energy Research Establishment, England (Oxford) at the International Conference on the Peaceful Uses of Atomic Energy (Chamberlain et al., 1955). In this, they have given what they believe to be maximum permissible levels of fission products in herbage grazed continuously by dairy cattle (Table VII).

TABLE VII
PROVISIONAL MAXIMUM PERMISSIBLE LEVELS OF FISSION PRODUCTS IN HERBAGE GRAZED CONTINUOUSLY BY DAIRY CATTLE

Fission product	Hazard to	Herbage (uc./g.)	uc./m.^{2}	Deposition (uc./m.^{2}/day)
I^{131}	Thyroids of cattle	$2X10^{-4}$	$4X10^{-2}$	$4X10^{-3}$
	Thyroids of infants consuming milk	$2X10^{-4}$	$4X10^{-2}$	$5X10^{-3}$
Sr^{89}	Skeletons of cattle	$9X10^{-4}$	$2X10^{-1}$	$1X10^{-2}$
	Skeletons of infants consuming milk	$4X10^{-4}$	1	$8X10^{-3}$
$Sr^{90} + Y^{90}$	Skeletons of cattle	$1X10^{-5}$	$2X10^{-3}$	$2X10^{-4}$
	Skeletons of infants consuming milk	$5X10^{-6}$	$1X10^{-3}$	$9X10^{-5}$

EXTERNAL RADIATION EFFECTS

The beta particle, because of its lack of penetration or, said in another way, because its energy is totally absorbed by small thicknesses of skin, cannot cause total body irradiation death. Massive doses applied to great surfaces of the skin may cause death. The radiologic action is like that of all ionizing radiations subject to energy (quality of radiation) and dose.

The first casualties of nuclear weapons were cattle exposed to beta radiation of fallout at Alamogordo (Bird, 1952). Except for the superficial skin lesions, these cattle lived a normal productive lifetime. Horses too, have been recipients of "beta burns" caused by fallout on the gunnery range at the Nevada Test Site.

Particulate matter of fallout, containing radioactive elements, when lodged on the hide or in the coats of animals may be close enough to deliver large doses of beta radiation to the skin.

The external or contact effect due to fission product decay during or following nuclear detonations is principally the result of beta radiation. Particulate matter lodging on the coat or skin of the animal brings the radioactive elements into position sufficiently long enough to produce what has been called "beta burns." One marked difference between thermal burns and beta burns is the immediate response to the former and the latent response to the latter. Several days or weeks may pass before physical signs of the beta burns are apparent. The lesions may be classified as:

(a) Epidermal atrophy which follows a low dose of radiation. Although a slight depigmentation of the coat may be seen a few weeks after exposure, the skin is usually intact and atrophy recognized only microscopically.

(b) Exfoliative dyskeratosis which follows a more intensive exposure, in which the skin becomes flaky and exfoliated. A chronic radiation dermatitis usually follows this type of burn. Atypical cell forms are characteristically found in the epidermis, hair follicles are usually destroyed, and the surrounding tissues produce a depigmented coat color.

(c) Transepidermal necrosis, the severest type of beta burn which except for the latent development mentioned above, resembles a thermal burn with edema, bullous desquamation, and loss of hair. An atrophic epiderm may eventually cover the lesion but the coat will not regrow. Around the edges of such a wound may be found the lesions characteristic of the two lesser types of beta burns.

Experimental beta irradiation of domestic animals has been reported. We (Trum, 1955) produced beta burns in burros, horses, and cattle which were characterized histopathologically by a sudden change from normal circumferential tissue to affected tissue, disturbance of melanin distribution, absence, obliteration, or shallowness of rete pegs of epiderm, destruction of hair follicles, and atrophy of dermis except in the periphery of lesions where there was a hyperplastic down growth of epithelium. Doses of 20,000 to 30,000 rep of P^{32} beta particles produced lesions in 20 to 100 days. Healing occurred in all cases but the skin of the area was denuded and atrophic while white hairs appeared around border of the lesions.

Having clipped the wool from one side of yearling lambs, both sides were exposed to doses of gradients from 1000 to 30,000 rep. On the clipped side, doses above 3000 rep produced visible lesions; others did not. Although observed for 100 days, no lesions were seen on the side exposed while the wool was on, lesions were noted on the 25th post-irradiation day in some of the shorn sheep. No lesions were produced when exposure was made through wool at the 5000 rep level and only pink discoloration of skin and loss of some wool resulted at the 20,000 and 30,000 rep level.

George et al. (1954) applied phosphorus and strontium plaques (P^{32} and Sr^{90}) to the skin of sheep whose wool had been sheared. Their results were similar to those produced at Oak Ridge with one notable exception. Suffolk sheep accumulated pigment in healed lesions giving the fleece a darker appearance than normal. Lushbaugh and Spalding (1957) have described in detail the histopathology of beta burns in sheep and concluded, after experimentation, that sheep are naturally well protected from beta radiation damage from fallout by the thickness of their wool.

LIFE SHORTENING OR PREMATURE AGING

The sum total of radiobiologic investigations is to determine the effect on life. Criteria other than death are informative but anticlimactic. Lethal dose studies on mammals follow the usual biologic response curve of a sigmoid type (see Fig. 1). The curve of acute radiation death is steep and there is a minimal acute radiation dose below which death is not imminent.

It has been suggested by many that the evidence indicates that: damage to the surviving animals has been done; some of this damage is reparable while some is irreparable; various species have characteristic repair rates; the irreparable damge is accumulative; and a measurement of these actions and total accumulative damage can be designated in terms of life shortening.

Blair (1952, 1953, 1954), Sacher (1950, 1955), Yockey (1956), Dancoff and Quastler (1953), and Mewissen et al. (1957) have suggested mathematical expressions of functions which are attempts to derive the per cent of repair and accumulative damage for each radiation event for each species.

This is done in an attempt to extrapolate to man with tha hope that a true tolerance level of radiation might be established. The "tolerance level" is that amount of radiation above background, which has not caused demonstrable biologic injury, regardless of criteria used and which, therefore, may be considered "safe."

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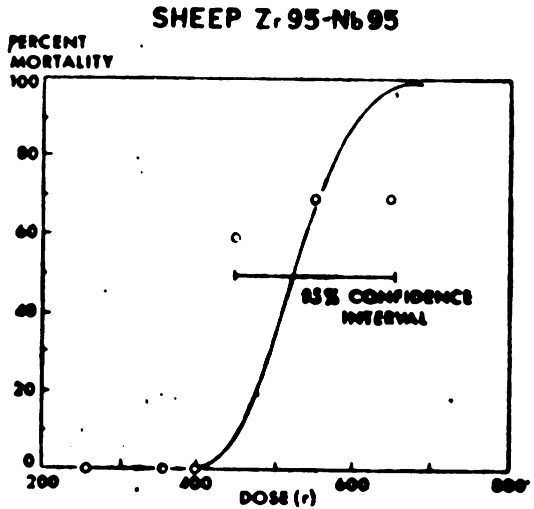

FIG. 1. The steep sigmoid curve characteristic of $LD_{50/30}$ irradiation experiments. The sheep were exposed to gamma radiation for Zr^{95} Nb^{95}.

Dr. TRUM. And now I should like to proceed with some slides, if I may.

Representative HOLIFIELD. You may.

Dr. TRUM. The first slide is the picture of the back of an Alamogordo cow. This cow lived a normal and useful life, although this was the first true effect of nuclear warfare on living creatures as far as we know. These are the only visible lesions. These happen to be the only effect it had on this particular cow. She lived and produced very well for the rest of her life, along with the herd.

Representative HOLIFIELD. Do you know what dose of radiation she had?

Dr. TRUM. The beta radiation to the back was in the order of 30,000 to 40,000 rad. Her total body radiation was probably less than 200 r.

Senator ANDERSON. What does the discoloration come from?

Dr. TRUM. The discoloration comes from the disfunctions of certain cells in the epiderm. The cells are unable to produce perfectly pigmented hair. In some animals, it turns black rather than white, but it is just a pathological effect of the radiation on the epiderm.

The next slide shows that regardless of the type of radiation used, and regardless of the animal, most of the LD 50/30 for animals fall in the same category. Their relative LD 50/30 is more or less the same within a certain range. Few animals survive exposures above a thousand r., and few die with lower than 250 r.

May we have the next slide?

This shows the conditions of one set of animals with radiation of different energies. It shows that, for example, the higher energy was less effective on the burro. Radiations of lower energies were more effective. And it also gives an explanation for the differences in LD 50/30. These were all burros. All were kept under the same conditions. All gave different results when the sources were varied. But regardless of the different results, they all come in the same pattern, As you can see, there is statistical significance here at the 95 percent confidence level.

May we have the next slide, please?

This slide shows that when large doses of radiation are given, that is, 340 up to 600, at about 1 r. an hour, swine did not die. They took those large doses without any apparent effect. But when they were irradiated again, we could measure the effect of that first dose in those high dose ranges. And we also note that we are approaching the point at which we would not have been able to measure any kind of an effect with that kind of an animal. In other words, had we given 200 r., we would not have been able to differentiate from the controls and those that had 200 r.—the difference of life span—would have been immeasurable.

These are, as I said, controlled experiments.

Another very interesting thing being that the swine, although their LD-50 is about the same as that of the burro, seem to have a fast recovery rate and were able to live in the reirradiation period upward of 200 to 300 days at 50 roentgens per day. In other words, they accumulated about 15,000 roentgens of total body exposure at that rate, whereas the burro, on the other hand, would only accept about 1,500 at the same rate. So there is quite a difference, not in the sensitivity of the animal as you saw it, but in their ability to recover. Any unquali-

fied extrapolations made from animal data are dangerous, as you may readily see.

However, under certain conditions, it would be easy to measure the amount of injury within a certain range, and that dose, or exposure, range is high. Below that range, the difference in life span is going to be difficult to detect.

Senator ANDERSON. How successful are you in extrapolating to mean from any known animals you have worked with?

Dr. TRUM. I think you heard the extrapolations the other day, and I would hate to go any further than those people, whom I consider very capable. These are the best data that we have in large animals, and they put more faith in the poor data they have on man than they put in the good data on animals, because the extrapolation is so risky. I think that is a fair statement.

Representative HOSMER. The larger the animal, the less the dose?

Dr. TRUM. The size of the animal has nothing to do with it. The size of the animal is not a factor, providing you do not bring in other factors; for example age, such as a calf and a cow, or a piglet and a hog, or something like that.

Representative HOSMER. How about your hamsters on the previous chart?

Dr. TRUM. The hamster happens to be relatively insensitive. He is a resistant species. However, you take a small quinea pig, and he is sensitive. So it is not the size. It is some chacteristic of the species and not the size.

Senator ANDERSON. Did you have any experience with cows at the Nevada Proving Ground? You showed Alamogordo. Did the Nevada cattle verify the thing you learned at Alamogordo?

Dr. TRUM. They are exactly the same, except that we have not as yet had any high doses of that range. Some cattle that were within 10 to 12 miles of the site at the time of detonation got about one-tenth the beta dose.

Senator ANDERSON. At Alamogordo there was a similar short and at Nevada many exposures. But the results were comparable?

Dr. TRUM. The results were comparable. I think somebody said yesterday—and it would bear repeating—that so far in the history of the Alamogordo and Nevada test sites, unless you can see the particles at the time of fallout, you would expect no result.

Representative HOLIFIELD. Could we reasonably expect a large death rate among meat animals, cows, pigs, other animals that men depend upon for food, under the pattern of this attack?

Dr. TRUM. Yes.

Representative HOLIFIELD. How much would it take in a one-shot jolt or dose to kill a cow, for instance?

Dr. TRUM. Over a thousand. Over a thousand would be a 100 percent kill.

Representative HOLIFIELD. And how about a pig?

Dr. TRUM. About the same. They are all about the same.

Representative HOLIFIELD. And chickens and rabbits?

Dr. TRUM. Chickens, a little higher.

Representative HOSMER. What is the situation as to the animals that causes this difference?

Dr. TRUM. Some have said it is the metabolic rate. But this has not been demonstrated, because if you slow down the metabolic rate, for example, in certain hibernating animals, the same animal will last longer. But actually, he does not stand much more chance. But if one were to take the same animal, slow down his metabolism, and irradiate him, he will last longer and stand a higher dose than otherwise.

Representative HOSMER. But you say that is not the general thing. What is that?

Dr. TRUM. I think this is as close as we know. It is probably the metabolism. But I qualify that by saying that I have nothing more to offer than our observations. Measuring the metabolic rate in a species and then measuring the effects on another family of the same species with a slower metabolic rate would have to be done in order that we may be sure we are dealing with a single factor.

Representative HOSMER. It is not a matter of difference in respiratory systems or some other system?

Dr. TRUM. No.

Representative HOLIFIELD. How about the relative amount of bone marrow in two animals of the same size? Would there be a difference in the recuperative powers?

Dr. TRUM. Not percentagewise, no, sir.

May we have the next slide, please?

Now we are getting into the bone marrow effects and the hematological effects. We have a difference in the clotting time of animals that have been irradiated which parallels, nearly, the fall in platelets. These are good indications, probably one of the best indicators we have, as to whether an animal that is suspected of being irradiated has truly been irradiated in the lethal range.

May we have the next slide, please?

In some swine we have produced leukemia.

I am sorry. I would have to qualify that. Leukemia followed irradiation. And it has not been done in sufficient numbers to know whether this is a product or not. Approximately one out of every 20,000 head of swine to go through the slaughterhouse has leukemia.

Senator ANDERSON. What is that?

Dr. TRUM. 1 in 20,000 has leukemia or lymphoma.

Senator ANDERSON. How many have you tested?

Dr. TRUM. The number of swine that has been tested is something like 100 in this particular case.

Senator ANDERSON. I was trying to find out how you got your figure of 1 out of 20,000.

Dr. TRUM. That is the number observed that comes through the slaughterhouses of the country that are inspected. Normal swine, in other words.

Now, we have an interesting thing. We see the platelets drop off immediately following the radiation, and it takes them about 2 years to get back to their proper level.

Representative HOSMER. What is a platelet?

Dr. TRUM. A platelet is a constituent of the blood, a thrombocyte. The next one?

The red blood cells, on the other hand, make a very rapid recovery. They drop off less slowly than the white blood cells, but make a rapid recovery. At the end of 18 weeks, all that are going to live have

recovered and are doing well, even in those ranges where some of them have died.

This particular slide shows that this is not true of the white blood cells, which take a few years to get back to normal. And the next one I think is an extension of this, and shows that after 2 years—and we followed some of these out to 3 and 4 years—they did have some noticeable effects.

Is that the last one?

Thank you very much.

The immune bodies of the animals also are affected by irradiation, and we would expect that the immunity toward virus, toxins, or bacteria will be affected in an irradiated group, but not in the same manner. There would be a difference in the response.

Radionuclides within the body of the animal produced their results as partial or total body irradiation. In this particular situation about which we are talking they will be the same as the total body. In other words, we will expect little damage in an animal that survives. Animals do not live long enough to develop all of the things that have been brought out as radiation sequella in the human. We do not keep them around to get the doses necessary. The genetics effects will be just as great and probably greater than those in man. But we are used to that. In animal populations we use these mutations in some cases, and in others we let them abuse us. All of us know that the species of dogs running around are certainly results of bad mutations, and I hesitate to name species. The Apaloosan horse, for example, occurs because we allow a certain type of gene to remain in the horse population. It is the same with the cattle, we are spending a great deal of money now trying to eliminate dwarfism in cattle that we propagated by selections.

So that we are used to that. And in the animal population we are not going to be worried about it.

Senator ANDERSON. What did you say about the Apaloosan horse?

Dr. TRUM. The Apaloosan horse is also the result of a genetic change.

Senator ANDERSON. The spots on the back of it?

Dr. TRUM. Yes.

Senator ANDERSON. The horses draw premium prices. I just wondered.

Dr. TRUM. Yes, they do. If we get something unusual in the animal line, unusually attractive in some people's estimation, or unusually useful in another instance, we use it, in spite of the fact that it might have been produced by a lethal gene in the wild and would eventually lead to the death of the strain.

There have been suggested maximum permissible levels for animals. But all of these maximum permissible levels are based on the effect of people using this animal. In other words, they are permissible levels for people. The permissible levels for animals have not been worked out, and I do not think that the permissible levels for the animal itself are going to be any criteria. I think from previous testimony, particularly of Gordon Dunn, it has been shown that some of these short-lived isotopes will amount to total bodily irradiation within the animal, and we will not have him around long after he is in that situation.

There is an interesting correlation about beta radiation lesions. I think we can now conclude from our past experience that if the animal has beta burns and lives, he will be all right. It is possible that they may get beta burns and die within 3 weeks, showing they not only were in the beta burn area but that their total body gamma exposure was higher.

If there are no burns at the end of 3 or 4 weeks death from total body irradiation, is highly improbable.

I think I have taken enough of your time. The rest is rather a summary of what I contain in the rest of the paper.

If there are any questions, I shall be glad to answer them.

Representative HOLIFIELD. Are there any questions?

Senator ANDERSON. I wish I had time to go through your paper. We may think of some things that we will want to submit to you. It is extremely interesting, I think.

Representative HOLIFIELD. Our next witness is Dr. Robert Reitemeier of the Department of Agriculture and the Atomic Energy Commission. He will present testimony on the effects of nuclear war on soils and crops.

Dr. Reitemeier is a soil scientist with the Biology Branch, Division of Biology and Medicine, U.S. Atomic Energy Commission and the Soil and Water Conservation Research Division of the Department of Agriculture.

The Chair wishes to recognize the cooperation of Dr. Ronald Menzel,[1] head of the Soil-Plant Relationships Section, Department of Agriculture, in the preparation of this testimony. This will be so entered in the record.

Dr. Reitemeier, we are happy to have you before us again.

STATEMENT OF R. F. REITEMEIER,[2] SOIL SCIENTIST, U.S. ATOMIC ENERGY COMMISSION AND U.S. DEPARTMENT OF AGRICULTURE

Dr. REITEMEIER. Thank you, Mr. Chairman. It is a privilege to be invited here to address you again on this subject.

The postulated nuclear attack, while not aimed specifically at agricultural targets, would have serious effects on the agricultural resources and food production in the United States. The damage to agriculture would include immediate and delayed effects on soils and crops.

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[1] Since July 1957, head, Soil-Plant Relationships Section, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Md. Born on Jan. 23, 1924, at Independence, Iowa. Graduated from Independence High School, 1940. Bachelor of science (agronomy), Iowa State College, 1947. Doctor of philosophy (soils), University of Wisconsin, 1950. Since 1950, soil scientist with U.S. Department of Agriculture, Beltsville, Md. Since 1952, has conducted investigations on the behavior of fission products in soils, their uptake by plants, and land decontamination procedures. Member of Soil Science Society of America, American Society of Agronomy, International Society of Soil Science, American Chemical Society, and the American Association for the Advancement of Science.

[2] Since November 1956, soil scientist, Biology Branch, Division of Biology and Medicine, U.S. Atomic Energy Commission, Washington, D.C., and Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Md. Born at Logansport, Ind., on Jan. 24, 1912. Graduated from Logansport High School, 1929. Bachelor of science (chemistry), Purdue University, 1933. Master of arts (chemistry), University of Missouri, 1934. Doctor of philosophy (agricultural chemistry and soils), University of Arizona, 1938. Shell Oil Co., Wilmington, Calif., technologist, 1938–39. U.S. Salinity Laboratory, Riverside, Calif., chemist, 1939–45. U.S. Department of Agriculture, Beltsville, Md., soil scientist, 1945–53 and 1954–56. Foreign Operations Administration, Alaska, Turkey, soils technician, 1953–54. Member of Soil Science Society of America, American Society of Agronomy, International Society of Soil Science, Washington Academy of Sciences, New York Academy of Sciences, Phi Upsilon, Phi Kappa Phi, and Sigma Xi. Soils editor, Biological Abstracts, 1946–53. Associate editor, Atomic Energy and Agriculture, American Association for the Advancement of Science, 1957.

Depending on the distance from ground zero, crops growing in a circular area around a burst would be damaged or destroyed, by blast and thermal radiation, and their associated effects, winds and fires. The extent of the area beyond this which would be swept by fires would depend on the weather, the location of fire breaks, and local firefighting capabilities.

The bomb fragments and the materials taken from the ground into the fireball and mushroom cloud are radioactive from fissionable materials, fission products, and neutron activated elements. Within hours following the attack, agricultural land downwind from the bomb bursts will be subjected to deposition of local fallout. During succeeding days and weeks the Nation's farmlands will receive deposits of tropospheric fallout from the attack and counterattack detonations. For years afterwards, stratospheric fallout will be deposited countrywide and around the world.

Representative HOLIFIELD. Doctor, at that point I want to go back to your second paragraph.

Of course, we realize that our pattern of attack presented all ground bursts. We had some very interesting testimony that if a 10-megaton bomb were exploded 50 miles above the earth, there would be something like 5,000 square miles of scorched earth under that one bomb. This would mean that all the crops in that 5,000 square mile area would be destroyed.

Dr. REITEMEIER. I did notice a report on that, but I wast not here to hear that testimony.

Representative HOLIFIELD. That is certainly a factor. And there was also some very interesting testimony on the effect of the light on the eyes from high bursts.

Dr. REITEMEIER. Yes, sir. It would seem reasonable that a high-altitude burst would have effects of this nature beyond the area indicated here for the ground bursts.

The time available did not permit a compilation of the areas of agricultural land and crops damaged by immediate effects and by local fallout. However, virtually the entire region east of the Mississippi River would be affected to moderate or severe degrees necessitating restrictions on farming operations and crop use, land decontamination, and shifts in crop production.

On the mid-October date assumed for the simulated attack, the harvests would be completed for a number of major crops, including oats, barley, rye, rice, peaches, Winter wheat, and tobacco, and nearly complete for hay, vegetables, dry beans, and Spring wheat. In a year of normal weather, other crops would be in about the middle of the harvest period, for instance corn, soybeans, apples, pears, grapes, grain sorghum, cotton, and flax. A large fraction of the Nation's annual crop production, therefore, would have been removed from the land before the attack and thereby protected from contamination by fallout. However, citrus fruits, fall potatoes, sugarcane, and peanuts would not have been harvested, and the harvest of sugarbeets and nuts would have just begun. In most areas, livestock would still be feeding on pastures and grazing lands.

Representative HOLIFIELD. Doctor, you speak of hay having been harvested. It would probably be baled, right in the same field. Would that make any difference?

Dr. REITEMEIER. If baled, certainly the external part of the bale would be contaminated. In this case, we could expect the inner parts to be safe and perhaps in the center completely protected. The same would be true in a stack, whether covered by tarpaulins or uncovered. The outermost part of the stack would be contaminated, the inner parts to lesser degrees, and probably completely protected in the center.

The next section is on effects and behavior of fallout.

Radioactive fallout deposited on agricultural land will contaminate food chains with radioisotopes by way of the soil and crops, and may, depending on the radiation intensity level, prevent farmworkers from the proper handling of crops, and cause radiation injury to perennial plants such as trees and vines. The last two effects would usually result only from local fallout, and the last only in heavy fallout zones. The deliberate exposure of workers to radiation in order to save contaminated crops that were not essential or might be discarded later would not be warranted.

Fallout particles may drop on plants or on soil. Those which are deposited directly on food and forage plants contaminate them by remaining attached to the above-ground parts, or by releasing radioisotopes which are absorbed into the leaves and other parts. In long-established grass pastures, radioisotopes may enter the plants through the roots and stem bases in the root mat lying above the soil surface. Rain and wind move particles from plants to soil, but the retention of the smaller particles exceeds that of the larger ones. Certain characteristics of leaves, such as hairiness and roughness, enhance the retention while others, for example waxiness, reduce it.

Short-lived isotopes are contributed almost entirely by local fallout, the longer lived isotopes also by local fallout but additionally in tropospheric and stratospheric fallout. In the heavy fallout zones, most of the longer-lived isotopes are deposited as local fallout. Because of the time required for movement into the root zone, shorter lived isotopes, for example iodine 131 and iodine 133, and barium 140, enter plants primarily through leaves and root mats. Radioiodine is readily absorbed into leaves; long-lived cesium 137 also is absorbed readily through leaves, but is taken up from soil by roots to only a limited extent. Strontium 89 and strontium 90, however, are absorbed relatively rapidly from soils, but at a relatively slow rate directly by leaves and fruits.

For the particular date and attack pattern postulated, salvage of much of the yet unharvested crop would be impaired by crop contamination, external exposure hazard, and unavailability of fuel and machinery. Farming activities during the succeeding months would be far below normal, generally throughout the country. Consequently, the land contamination problem in heavy fallout zones would be primarily a soil contamination problem, that is, a long-term hazard.

Erosion of soil and runoff of water move deposited fallout and radioisotopes down slopes to lower lying areas where they may accumulate in concentrations exceeding those in the upland soil. This effect would be aggravated by the burning of crops or crop residues or by inadequate soil management. Areas subject to accumulation should be monitored frequently, especially if used for crop production.

Most of the radioisotopes moved downward into the soil through leaching with water very slowly. Other channels of movement are soil cracks, worm casts, and animal burrow holes. Most of the fission products and other fallout isotopes are cations, positively charged atoms, which become attached to the surfaces of soil particles, and are subsequently removable only by replacement with other cations or by acids. The fallout cations generally are held very tightly, for instance cesium 137 by what is called nonexchangeable fixation. On the other hand, most or all of the strontium is held in a readily replaceable form.

Of the longer lived fallout isotopes, strontium 90 is taken up from soils by plants to the greatest extent. Others, for instance, zinc 65, cerium 144, ruthenium 106, promethium 147, cesium 137, and plutonium 239, are absorbed in amounts ranging generally from one-thousandth to one-tenth that of strontium 90. Radiostrontium behaves in soils and plants similarly to the essential nutrient element, calcium. Little or no discrimination between the two elements occurs in their uptake by plants when they are uniformly distributed in the root zone. The strontium-to-calcium ratio in crops grown in the field, however, depends on the distribution of strontium and available calcium in the soil profile within the root zone. When the predominant intake pathway is uptake from soil, high calcium crops will have high contents of strontium 90, and low-calcium crops on the same land will have low contents. For example, alfalfa and clover have higher calcium contents than the grasses, and cabbage and lettuce have higher contents than apples and potatoes. The substitution of foods of low calcium and strontium content for foods of high content is of little or no benefit, however, unless the diet is supplemented by an uncontaminated source of calcium.

The next section is entitled "Management of Contaminated Land and Crops."

Decontamination of crops harvested for human consumption in the weeks following the attack will be necessary. Crops from zones of heavy fallout will require a high degree of decontamination. Simple measures such as washing or discarding outer portions of items for human consumption would be advisable in all areas. The degree of decontamination of food items depends upon the care used in separating the exposed from the unexposed parts. First, the exposed parts must be thoroughly washed to dislodge fallout particles, and then removed in such a way that hands or utensils do not contaminate other parts. It should be possible to achieve complete decontamination by successive parings of crops such as apples or cabbages, washing the hands and utensils before each paring. This type of decontamination could be applied to many human food items in the home if clean water were available.

Decontamination of soils is required only for the removal of strontium 90. Other biologically significant fission products either are taken up from soils in much smaller amounts or have such short lives that decontamination is not necessary. In zones of heavy fallout, decontamination will be required to reduce the strontium 90 content of the soil to a level acceptable for production of vegetables and milk. For production of other crops, or in zones of lighter fallout, it may be sufficient to use practices which reduce the uptake of strontium 90 to a lesser degree.

Methods of land decontamination include removal of crops, mulches, or other types of ground cover, removal of surface soil, leaching, and intensive cropping. Practices which sometimes reduce the content of strontium 90 in food products include adding soil amendments, plowing below the root zone, and changing the type of farm production.

Decontamination by removal of ground cover is effective in proportion to the density of cover. The cover provided by sod or a mulch consisting of two tons of oat straw per acre is practically complete. More than 90 percent of the fallout on such cover may be removed by cutting the sod or raking off the straw. Standing crops usually provide less complete ground cover, especially when young, and their harvest may remove only a small fraction of the fallout. Contaminated crops could be disposed of by baling or burning to reduce their bulk. The bales or ashes must be stored where they will not contaminate other foods.

Senator ANDERSON. May I stop you there and ask you what you mean when you say, "The cover provided by sod or a mulch consisting of two tons of oat straw per acre is practically complete. More than 90 percent of the fallout on such cover may be removed by cutting the sod or raking off the straw"? When you say "the sod," are you referring to a pasture, for example? What would you do with the sod after you cut it and rolled it up?

Dr. REITEMEIER. As mentioned in succeeding paragraphs, this is an important part of the problem.

Senator ANDERSON. Well, what would you do with it?

Dr. REITEMEIER. This might be put into ditches adjacent to the field or occupying a part of the field. The volume of material involved would necessitate its being disposed of somewhat locally, because it would be hard to conceive of transportation to any considerable distance.

Senator ANDERSON. Well, in an area such as that which the gentleman from California lives in, would it not be virtually impossible to cut the sod and remove it? Where would you put it?

Dr. REITEMEIER. This would mean a reduction of your arable land. A certain percentage of your arable land probably would have to be used for disposal of contaminated material.

Senator ANDERSON. Some of those buildings they said would have to stand there unoccupied for 200 years. Would it be contemplated that a pasture, a golf course, or something like that would have to stand unused for a long period of time, 50 or 100 years?

Dr. REITEMEIER. We offer only slight hope of any great beneficial effect of weathering. If the strontium was deposited on the ground and no decontamination measures were taken, natural weathering would not dissipate or remove that strontium very far, probably, in decades.

Senator ANDERSON. So that means that in an area like Wisconsin, which is a great dairying country, or Minnesota, those pastures are going to have to be unused for a long, long time, because of the possibility of contamination of milk?

Dr. REITEMEIER. We are referring here particularly to the higher fallout intensity zones.

Senator ANDERSON. You just could not possibly remove the ground cover from the Wisconsin pasture or Minnesota pasture and put it anywhere; could you?

Dr. REITEMEIER. In the particular exercise here for Minnesota and Wisconsin we are not suggesting that you have a problem of this magnitude for those two States.

Senator ANDERSON. You would have them sent some place where there was not such good pasture? They might not do it. I am trying to find out just what you would do. Is it a fair statement to say that there is no known method by which you can remove the contamination from a pasture area? There is no substance that you can supply? You cannot leach it out of the soil like you can alkali?

Dr. REITEMEIER. This is probably at least equally difficult as the leaching of alkali. You might use the same treatments in some areas for this as you would for alkali. So they would be equally difficult.

Senator ANDERSON. If you have ever tried leaching out a field that contains alkali, you know you have a very long process.

Dr. REITEMEIER. In certain areas it would be very difficult and time consuming.

Representative HOLIFIELD. This certainly points up a tremendous problem for our food source lands in the event of a nuclear war; does it not?

Dr. REITEMEIER. It certainly does, in a large fraction of the country, in this case especially the eastern part.

Representative HOSMER. Do you mean that the degree of strontium 90 contamination that would make the land unusable would occur in 50 percent of the land area of this country? You certainly do not mean that, do you? That does not coincide with any other figure we have had.

Dr. REITEMEIER. The percentage of the total land area or of the agricultural land which would be contaminated to the highest extent by strontium 90 is a small percentage. As I said, it has not been possible in the time available to make even approximate calculations, but the area may be of the order of only a few percent, which would have the highest amount of strontium 90.

After any attack such as this, we could say that probably the amount of land needed might be somewhat lower than what we are using at this time.

Representative HOSMER. In the consideration of these contamination possibilities, has there been any work done to discover plants which may have a particular affinity for strontium 90 or some other product which could be planted as a decontaminating agent?

Dr. REITEMEIER. We have no positive evidence of any plant so far which we could use for this purpose.

Representative HOSMER. I did not ask you if you had any positive evidence. I asked if you had any program directed toward it.

Dr. REITEMEIER. We have had, of course, experiments with a great variety of commercial crops by various people, and among all these experiments there has been, as far as I know, no outstanding crop of this type.

Representative HOSMER. You have no crop that would be a real strontium seeker?

Dr. REITEMEIER. Not to any appreciable degree. There are some differences between crops.

Decontamination by removal of surface soil is most effective if the surface is originally smooth. Rough freshly plowed surfaces are more difficult to decontaminate. Scraping off 2 inches of soil with a road grader may remove over 99 percent of the fallout in the first case, and only 60 percent in the second. Rough soil surfaces may be decontaminated more thoroughly by scraping off more soil. Surface coatings of adhesive materials might be applied to entrap the fallout particles and then removed together with only a thin layer of soil. No method of picking up such material on a large scale has been devised. The safe disposal of contaminated surface soil is a serious problem. For the large volumes of soil involved, the only practical places for disposal appear to be pits in the center of small fields or regularly spaced ditches across the fields. The pits or ditches would have to be protected from erosion and not used for crop production.

Leaching of soils to move strontium 90 below the root zone of crops would have only a limited application. During leaching, calcium and other plant nutrients would be leached out of the root zone, and would have to be replaced. Leaching is most effective on sandy soils, using water containing calcium or acids. The calcium could be supplied by first spreading gypsum on the surface. Even for sandy soils, heavy applications, of the order of 100 tons per acre, would be required, and more than 4 feet of water would have to percolate through the soil. For loam or clay soils, even more gypsum and water would be required.

For most crops and soils, about 1 percent of the strontium 90 in the soil is removed in a single crop. On sandy soils, some crops may remove as much as 5 percent. Even at this rate, more than 40 crops would be required to achieve 90 percent decontamination of the soil.

Representative HOLIFIELD. That means 40 years?

Dr. REITEMEIER. That is in areas which have one crop per year, yes.

Strontium uptake by plants or the strontium-to-calcium ratio sometimes can be reduced by applying lime, limestone, or gypsum to the soil. In order to be effective, the addition must increase the available calcium supply in the soil. At best the strontium uptake can be reduced to about one-half of the uptake if the soil were not so treated. Lime and limestone will be most effective on very acid soils, and gypsum on soils containing large quantities of exchangeable sodium. Such soils need lime or gypsum regardless of the strontium 90 hazard.

Applications of fertilizers or large amounts of organic matter may also reduce the strontium 90 content of the crop, but to be effective over many years the high treatment levels must be maintained. These practices also reduce the calcium content of the crop. When such crops are eaten, the retention of strontium 90 in the body will be almost as high as though the fertilizers or organic matter were not applied, unless supplemental calcium is included in the diet.

Deep plowing can place strontium 90 out of reach of some plant roots. However, the roots of most crops extend through the entire depth of plowed soil. With shallow rooted crops, such as most grasses, deep plowing might reduce strontium 90 uptake to one-third of that without the treatment. Deep plowing will be most effective when the freshly exposed surface soil has a high supply of calcium, either naturally or by addition of lime or gypsum.

There are alternative uses for contaminated lands which do not require decontamination. Essential nonfood crops, such as cotton or flax, could be grown on contaminated land. Sugar and oil crops, or crops for meat production might be acceptable even when grown on land too badly contaminated to produce milk or vegetables. To the extent that it is possible to shift production of milk and vegetables to uncontaminated land, decontamination can be avoided.

It should be recognized that when contaminated lands are placed in cultivation by deep plowing or shifting to alternative crops, the possibility of physical removal of the fallout is gone. As a result, it may be impossible to return these lands to production of milk and vegetables for many years. Obviously, heavily contaminated lands should be placed in cultivation only when their use is absolutely essential.

Mr. Chairman, this completes my written statement.

Representative HOLIFIELD. Thank you.

Any questions?

Representative HOSMER. Doctor, under the hypothetical attack, here, we would probably find the insect eating animals and birds, relatively heavy sufferers, and the insects not heavy sufferers. Would we tend to find ourselves in an imbalance between the two and find ourselves in an insect ridden condition?

Dr. REITEMEIER. This would be one of the anticipated effects. Insects are relatively resistant to radiation, and it is commonly agreed that in this type of situation the insects would probably be one of our foremost problems.

Representative HOSMER. Do you have any studies on it or any conclusions on it, or is it just recognized as a problem?

Dr. REITEMEIER. It certainly is recognized as a problem. I do not know that there has been much detailed analysis or any research. I think perhaps Dr. Wolfe may touch on this when he discusses the general effects on the environment.

Representative HOLIFIELD. Thank you very much, sir. You have painted a picture, here, which is quite a serious one, as to the usability of soil after such an attack. It presents great problems, and the problems appear to be ones that will last for many, many years in those areas of intensive fallout. Again I think we should say this would be in an area where I suppose you would get from 3,000 down to, say, 1,000 roentgens in the close-in fallout zone.

Or would this be based on the local fallout of long-lived isotopes?

Dr. REITEMEIER. It is hard to provide single figures for this, because most of us who are involved in estimating the effects and planning recovery measures for this type of problem feel that there should be no single value or single standard established, the overall situation should be the governing factor with respect to the acceptability of food for subsistence. The higher the level of contamination, certainly the higher will be the amount of contamination that will have to be lived with for subsistence purposes. So I would say your figure of 1,000 to 3,000 roentgens per hour zone down toward the 300 roentgens per hour zone is in general the level I am thinking of here as a main strontium contamination problem.

Representative HOSMER. It will take much more than that to destroy my faith that the American farmers can produce surpluses under almost any conditions.

Representative HOLIFIELD. Thank you, Doctor.

Our next witness, Dr. Edwin P. Laug of the Bureau of Biological and Physical Sciences, Food and Drug Administration, will discuss the impact of nuclear attack on processed foods.

Since 1950, Dr. Laug has been Chief of the Physiochemistry Branch in the Division of Pharmacology. He has been the director of three field studies at the Nevada test site investigating the effects of radiation and fallout on drug and foodstuffs.

Dr. Laug.

STATEMENT OF EDWIN P. LAUG,[1] BUREAU OF BIOLOGICAL AND PHYSICAL SCIENCES, FOOD AND DRUG ADMINISTRATION, DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Dr. LAUG. Mr. Chairman and members of the committee:

The Food and Drug Administration conducted extensive field studies on the effects of nuclear explosions and fallout on foodstuffs and containers in the 1955 and 1957 series at the National Test Site in Nevada. The results, which are unclassified, have been published in eight weapons tests reports. While the field exposures were made to relatively low yield fission type explosions, we believe that our findings on food can be made to apply at least qualitatively to megaton explosions, provided appropriate scaling factors are considered.

For these studies a board representation of the most frequently used items in the American dietary was selected. In addition the protective properties and effectiveness of a considerable number of packing materials were evaluated.

With respect to the foods, the following categories were examined:

(*a*) Bulk items such as sugar and flour.

(*b*) About 60 items including vegetables, fruits, meats, seafoods, soups, baby foods, evaporated milk, all heat processed in metal and glass containers.

(*c*) Bottled and canned beverages.

(*d*) Processed meats such as ham.

(*e*) Dried fruits and breakfast cereals.

(*f*) Frozen foods.

With respect to the packaging materials the following categories were examined.

(*a*) Hard items, such as steel and glass containers.

(*b*) Soft items, such as plastics, metal foils, paper, cardboard, and cloth.

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[1] Born Oct. 4, 1902, Philadelphia, Pa.

Education: Haverford College, 1925, A.B., chemistry; Haverford College, 1926, A.M., chemistry; University of Pennsylvania, 1930, Ph. D., physiological chemistry.

Professional career 1926–35: University of Pennsylvania, instructor in physiological chemistry; instructor in physiology; research associate in physiology. University of Tennessee: Research fellow in nutrition.

In 1935 when the Division of Pharmacology in the Food and Drug Administration was created Dr. Laug was appointed as a pharmacologist to investigate the toxicity of lead and arsenic insecticidal sprays. Since that time he has conducted researches on the newer organic insecticides with particular attention to methodology. Since 1950 he has been Chief of the Physiochemistry Branch in the Division of Pharmacology, and in 1951 became associated with the civil defense effort dealing particularly with radioactivity. He has been the director of three field studies at the National Test Site in Nevada, investigating the effect of radiation and fallout on drugs and foodstuffs.

Since 1956 he has been studying radioactivity in foods in relation to contamination by fallout.

He is the author of about 60 scientific papers published in professional journals.

Two exposure situations were examined.

(a) Target and fringe areas.

(b) Fallout.

A. Target and fringe areas. Justification for studies on target and fringe areas rests on two concepts:

1. In the target or fringe area it may be predicted that even close-in, modern reinforced steel and concrete food storage facilities might survive complete destruction, at least at ground and subsurface levels, and certainly in fringe areas. Accepting this assumption, it seemed reasonable to suppose that the remains of a warehouse could still contain important quantities of recoverable food. Such "islands" of food might be vitally important in the first few days or weeks after an attack, particularly when we may anticipate more or less complete destruction of long-distance transportation.

2. In a saturation bombing situation as here described, there is good reason to expect that the stratospheric fallout cloud may disperse itself downwind over other bomb drop areas. Therefore knowledge of the fate of food recoverable from the latter, and particularly knowledge concerning the integrity of the containers assumes vital significance.

Representative HOLIFIELD. Doctor, will you read just a little faster? We are running a little behind on our schedule.

Dr. LAUG. With respect to blast effects: We think these are overriding. Nearly all foods, whether bulk or processed, are encased in some type of container for shipping or storage purposes. It is therefore obvious that what happens to the container, whether the hard type (steel or glass) or the soft type (plastics, paper, cardboard, cloth), will determine the ultimate usability of the food encased therein. We may define the blast effects as primary and secondary. Under primary are included severe atmospheric pressure changes, and movement of the earth (ground waves). These phenomena can produce failure of seams and closures due to alternate compression and rarification of the atmosphere, or in the case of liquids, a destructive water-hammer effect or hydrodynamic surge within the container. Closely associated with these effects is also mutual crushing produced by the proximity of containers to each other in a case or carton. Paradoxically perhaps the soft containers may be less subject to this type of damage, because they are not airtight barriers upon which this effect depends. Instead of the crushing force of proximity, closely packed cartons of items such as flour sacks, breakfast foods, et cetera, may actually serve their mutual protection.

The secondary effects of blast are all due to the structural failure of the facility housing the food depot. Complete destruction of the upper floors of a warehouse located within 3 to 5 miles of an epicenter must be assumed. It may be theorized that the recoverable hard containers would fare much better than the soft containers, and for very obvious reasons.

Representative HOLIFIELD. Of course, in that type of radius, 3 to 5 miles, you have radiant fires which will do the job, anyway.

Dr. LAUG. That is right. I include, when I say fringe areas— these distances may go up to 10 miles. I am simply giving this as a reference in relation to target.

If we may project from our results which we found in Nevada, which were, of course, on fission weapons, we can say that in general, based on this extension, the following effects occur in the close-in area or the fringe area.

PROJECTED RESULTS

Based on an extension and extrapolation of the effects noted on foods and containers exposed in the Nevada test series, we can make a prognostication concerning the fate of processed foods located "close in to a megaton target area or its fringes."

First of all, all foodstuffs and containers would become radioactive. This is not a surface phenomenon resulting from deposition of radioactive dust. It comes about through the action of neutrons emitted briefly at the time of the blast. Neutrons penetrating the food convert atoms to radioactive species or isotopes, which then decay, giving rise to radioactivity. Foodstuff and containers are equally affected. However, the radioactivity of the container is not conveyed to the food it encloses in any significant degree. With the exception of the element phosphorus which has a half-life of 15 days, most of the intense radioactivity traceable to other elements in the food decays rapidly. In an actual situation it is probable that several days, possibly a week, would elapse before access to such an area would be possible. This would allow sufficient time for decay so that residual radioactivity should not in itself bar consumption of the food after this time if the container or wrapping is intact. Such a decision, it must be emphasized, rests on disaster conditions, and should certainly not be made in this way after conditions normalize and choice of uncontaminated food becomes possible.

BLAST EFFECTS ON CONTAINERS

On ground floors and particularly in basements where protection from violent and destructive displacement would be afforded, the overall failure of hard containers would be relatively small, perhaps of the order of 15 to 25 percent. Hidden damage to cap seals and seams would be minimal. In fact, it can be said generally that the more durable food packages and hard containers would fare much better than the structure in which they were stored.

With respect to structural failure, one important and interesting observation concerns missile damage. Slivers of glass and wood, bits of metal and stone assume the energy of bullets. Soft containers, such as flour sacks, are particularly vulnerable, and even metal cans will show the evidences of perforation.

OTHER EFFECTS

(*a*) *Heat.*—Excluding secondary fires, damage from the heat flash would be minimal because building walls and roofs could act as effective shields before the advent of the destructive blast wave.

(*b*) *Vitamin losses.*—These would be minimal in those foods close-in which would receive significant amounts of prompt radiation.

(*c*) *Acceptability.*—Radiation exposure would cause some deterioration in taste and odor. The most notable example would be powdered milk. Generally these changes would be minimal and go unnoticed except for those specially altered.

(*d*) *Chemical changes.*—Slight to moderate changes in fats would be noted, and could be characterized as oxidative reactions.

FALLOUT

The potentialities for contamination of the entire food chain by fallout overshadow all others. Actually prompt radiation and associated effects just described are only of minor importance when one compares the respective areas of action; a bombdrop only involves 10 to 25 square miles, yet the radioactive "tail," so to speak, may spread over thousands of miles downwind. Thus, with respect to packaged foods, the significance of the bombdrop and fringe areas lies in the degree to which packaging material has been destroyed, thereby subjecting the unprotected contents to fallout from another distant burst. Noting the fallout patterns described on the maps, it becomes clear that only a relatively few food depots would escape such action.

PROJECTED RESULTS

In a fallout situation uncomplicated by additional local damage, all of the container materials, with the exception of cloth and burlap would be adequate to prevent fallout dust from getting into a food package. In addition much protection would be offered not only by the building, but in the ordinary ways that cartons and boxes are stacked and palleted. Effective and simple means for removing fallout dust from the surface of packages are available, also modified ways of opening such packages, taking care to avoid seams. Excessive use of water, particularly in the pervious types such as paper is contraindicated, but this method together with detergents is highly effective on steel and glass containers.

When fallout will have occurred in an area already subjected to extensive physical damage, the chance of recovering uncontaminated foodstuffs, particularly those packaged in soft containers that have remained intact, is poor. It is conceivable that some "skimming" could be effectively practiced wherein the protecting layer of debris might be cleared away to uncover lower tiers of intact cartons, bags, cases, et cetera. With respect to the hard containers as exemplified by canned goods, both in metal and glass, the chance of recovering intact stocks is more encouraging. Hence, processed foods in cans or glass would certainly be the main items of choice in a nuclear disaster situation.

Representative PRICE (presiding). Thank you very much, Dr. Laug.

Our next witness, Dr. Kermit H. Larson, chief, Environmental Radiation Division, the University of California, Los Angeles, will present testimony on obervations of distribution characteristics and biological availability of fallout originating from actual continental detonations.

Dr. Larson has had extensive experience in field and laboratory. He participated in the Bikini tests in 1946, was Chief of Radiochemistry Unit, Atomic Energy Project, University of California, and was also Field Director of the Nevada Test Site fallout group.

Dr. Larson, would you proceed?

STATEMENT OF K. H. LARSON,[1] CHIEF, ENVIRONMENTAL RADIATION DIVISION, THE UNIVERSITY OF CALIFORNIA

Dr. LARSON. Thank you, sir.

Gentlemen, it is indeed encouraging to note the progress that has been made with respect to this very complex problem of environmental contamination. From 1946 to 1959, only a few of us were in this field of research of radiation ecology. Since then, much has been learned. However, as in the case of any field of research, many previously unrecognized problems are now ready for the effort available for their solutions. These and previous hearings by this subcommittee will contribute to the forthcoming answers.

With your permission, Mr. Chairman, I submit my prepared formal statement for the record.

Representative PRICE. Very well.

Dr. LARSON. I would like to spend the time allotted discussing certain highlights of the data and observations that we have made since.

During the last decade the environmental radiation division has been involved in progressively intensified programs designed to answer one principal question, viz, "How much manmade radioactivity distributed in the environment can be tolerated safely by man and his economy?"

The more specific objectives of our effort within this broad context include:

1. Delineation of fallout patterns and their characteristics with respect to particle size through which the mechanics of fallout can be more accurately defined. This, in turn, leads to a comparison of the effects of the yield of device detonated, type of device support, and the relation of the detonated device to ground surfaces upon the resultant fallout radiation intensity including the residual radioactivity per unit surface area within the fallout pattern.

2. A detailed study of the chemical, physical, and radiological characteristics of fallout debris relative to its particle size and occurrence within the fallout pattern.

3. Determination of the biological availability, rate of accumulation, and retention of the fallout debris in various native and domestic plants and animals, as well as the persistence and redistribution of residual contamination in the total environment.

The data to be presented are not directly applicable to the problems resulting from nuclear war primarily because continental testing has been limited to low yield devices. Further, tests have not been

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conducted to determine the consequences of fallout from weapons detonated over or on simulated metropolitan complexes. However, the studies that have been made on fallout from variously supported test devices may serve as a basis for establishing certain perimeters for the environmental effects of nuclear war.

Fallout phenomenology and its characteristics: Fallout from test devices detonated at Nevada Test Site is governed by many complex variables such as: energy yield; wind structure; the support used for the detonation of devices; ground surface; degree of fireball intersect with ground surface; and mass of inert material or shielding surrounding the device. The data represent the resultant effects, and characteristics of fallout from the various detonations studied by this laboratory are summarized in the following statements:

1. Detailed characteristics of fallout patterns: The coordination of aerial survey measurements of fallout patterns with ground survey meter measurements has greatly increased the detail and accuracy of fallout pattern delineation as well as the distances to which fallout patterns can be detected.

By use of aerial survey equipment and techniques as developed by the U.S. Geological Survey, fallout radiation intensities within an area of approximately 10,000 square miles can be measured in about 12 hours by one aircraft. Aerial measurements agreed within plus or minus 10 percent of measurements taken 3 feet above the ground by conventional survey meters. During the Plumbbob test series, fallout patterns were routinely measured to distances of 200 to 300 miles from ground zero; however, one fallout pattern from a tower-supported detonation was documented as far as 700 miles from the Nevada Test Site with the radiation levels readily detectable at that distance. See figures 1, 2, and 3 (pp. 807, 808, 809) in my prepared statement.

The detailed documentation of fallout patterns during the Plumbbob series, 1957, afforded the opportunuity to confirm the existence of "hot spots" in most all fallout patterns. Hot spots were first identified in 1948 when the fallout pattern of the Trinity detonation in New Mexico had been outlined in detail.

It is the opinion of the author that terrain features such as mountain ridges create a significant turbulence in the radioactive dust cloud as it moves over the ridge, causing an increased amount of fallout to occur on the leeward side.

We have examples on the next few slides.

This pattern is the Boltzmann pattern, which Dr. Lester Machta presented the other day. We were able to document this out to about 250 miles. You will note the coloring, the red being the maximum intensities. Again, the hot spot is occurring at approximately 80 miles from ground zero.

Diablo, another pattern that we worked, is a different configuration, but again the hot spots are showing up. Each of these are on the lee side of a mountain range. This pattern also demonstrates clearly the differences in wind strata that you might have present during a detonation. The Hood pattern we documented to 320 miles, extending a considerabel distance into Utah. Again the hot spot shows up at approximately 200 miles. This was a balloon shot mounted on a 1,500 foot balloon above the surface. It did not intersect the ground.

Then we have the Smoky pattern. This particular slide shows our detail that we have out to approximately 225 miles.

The next slide (fig. 3, p. 809) is the extension of this pattern out beyond Rock Springs, Wyo.

While the occurrence of hot spots has been associated with prominent terrain features in many cases, data are insufficient to fully explain their mechanism of formation and to permit their prediction. However, the radiation intensity contours of fallout patterns in general have been quite accurately predicted as illustrated by the Weather Bureau prediction and the measured pattern of shot Smoky, figure 4 (p. 811).

The heavy line is the forecast that we obtained from the fallout predicting group, and the lighter line is the actual measured documented lines.

It should be noted that quite radical deviations from "idealized" fallout patterns may result from local meteorological conditions. The example is shot Wilson.

The fallout from aerial bursts have not been detectable by conventional ground survey methods within 200 miles of ground zero. Two test devices detonated from balloons at 1,500 feet without the fireball intersecting the soil surface deposited less than 0.2 percent of the theoretical fallout activity.

The area that we use in this calculation is the area that is defined by the 1 mr. per hour radiation intensity contour (at H plus 12 hours) and between the distance of 1 mile from ground zero and the distance corresponding to a fallout time of H plus 12 hours. To illustrate the effect of the intersection of fireball, a balloon-supported shot which did intersect the soil surface deposited 2.12 percent of the theoretical fallout. However, within the 1 mr. per hour radiation intensity contour (at H plus 12 hours) and the same distance limits fallout originating from test devices mounted on steel towers whose fireball in some cases intersected the soil surface and in other cases did not, deposited 6.7 to 24.5 percent of the theoretical fallout activity.

In 1955, we defined the fallout particle predominantly found on vegetation. This we found to be the zero to 44 micron size. And for that reason we have emphasized this particle size range in our recent studies.

Within the limits of 1 mile from ground zero and to a distance corresponding to H plus 12 hour fallout time, test devices detonated on 500 and 700 foot towers had approximately 30 percent of the fallout activity associated with particles less than 44 microns in diameter. However, a test device of comparable yield mounted on a 700 foot balloon had 70 percent of the fallout activity associated with the same size fraction.

On the average, 38 to 50 percent of the radioactivity contained in the less than 44 micron diameter fallout samples from tower-mounted detonations was associated with the less than 5 micron diameter particles and 51 to 83 percent in the case of fallout samples from balloon mounted detonations. Various percentage contributions of less than 5 micron diameter fallout particles were observed at virtually all sampling locations for both tower and balloon mounted detonations.

Solubility is one of the most important properties of fallout with respect to the "internal emitter" problem in biological systems. As

indexes of biological availability, we arbitrarily use the solubility of fallout material in water and 0.1 N hydrochloric acid.

The fallout material from balloon-supported detonations was more soluable in both water and acid than that produced by other types of detonation. The solubility of fallout from tower-supported detonations increased with decreasing particle size. However, in the case of balloon-supported detonations, the smaller particles were somewhat less soluble than larger particles.

The distribution of fission products as of 30 days after detonation, with respect to different particle sizes of fallout, from tower and balloon detonation, is illustrated in this present slide (see table, p. 815). Fallout particles less than 44 microns had greater percentages of radiostrontium and radioruthenium at 30 days after detonation than did the larger particles.

The percentages of radiostrontium and radioruthenium in balloon-mounted detonation fallout were several times higher than in corresponding particle sizes from tower-mounted detonations. The reverse was true of radiozirconium. Radiobarium, radiocerium, and radiottrium varied to a lesser degree between tower and balloon shot fallout. Strontium 90 averaged 2.7 percent of total radiostrontium at D plus 30 days in fallout originating from detonations mounted on towers.

The widespread distribution of the less than 44 micron fallout fraction from all types of devices detonated at the Nevada Test Site indicates that this size fraction is probably the most significant with respect to total area of contamination and its potential biological availability.

A comparison of fallout from a balloon-mounted and a tower-mounted detonation having similar KT yield and the same detonation height of 700 feet indicated that over the distance having a 1 to 15 hour fallout time period, the amounts of water-soluble radiobarium and radiostrontium deposited by the less than 44 micron fraction of each detonation were similar despite relatively large differences in the level of the total radioactivity in this size fraction. The acid-soluble fraction was higher for the tower-mounted detonation.

The radiostrontium presents the same type of picture.

Now, this becomes important when one is evaluating the immediate fallout or that which we have been discussing in the last week, because there is a vast difference as to what might be available biologically.

The decay of fallout radioactivity: Fallout materials from a specific detonation had similar beta decay curves, regardless of particle size and time of fallout. Estimates of dosage in fallout areas have generally been based in part on the decline of dose rate, mr per hour. Beta decay curves of most detonations approximate the T to the minus 1.2 decay relationship over a period of H plus 12 to H plus 6,000 hours. However, slopes of the order of T to the minus 1.4 occurred from H plus 6,000 to H plus 10,000 hours.

Decay curves of the gamma emission rate were different from those of beta decay for fallout materials from a specific detonation. Gamma decay curves of fallout from different shots were generally similar, but more variable than corresponding beta decay curves.

Estimates of dosage in fallout areas have generally been based, in part, on a decline of dose-rate (mr per hour) with time according

to the t to the minus 1.2 relationship. A dose-rate decline with time according to the Plumbbob gamma decay (PGD) curve yields calculated doses which are 1.5 to 2 times greater than those calculated by the t to the minus 1.2 relationship from different fallout times to approximately 400 days after shot.

Deposition of radiostrontium in areas adjacent to Nevada Test Site: A balloon-mounted detonation, whose fireball intersected the soil surface, deposited approximately 0.13 percent of the total amount of Sr 89 produced within the area limits defined previously. Two balloon-mounted detonations, whose fireballs did not intersect the soil surface, deposited 0.004 and 0.008 percent within the above perimeters of the total amount of Sr 89 produced. Tower-mounted detonations deposited from 0.5 to 2 percent of the Sr 89 produced and from 1.6 to 7.2 percent of the total amount of Sr. 90 produced.

This means, then, that of the strontium produced by the detonations at Nevada, less than 10 percent remains within 200 miles. The 90 percent is somewhere else, perhaps, in the United States, or circling the world.

This fractionation of strontium 89 and strontium 90 with regard to particle size may be predicted on the basis of the different half-lives of their noble gas precursors, krypton 89 and krypton 90, and the physics and the chemistry of the particle formation.

Biological availability is the next section of my discussion this afternoon. And I will limit our figures, our statements, to that which we have observed out to 400 miles from NTS.

In the undisturbed areas, the radioactive debris from fallout is confined to the surface 2 inches of the soil profile even after 9 years following fallout contamination.

This particular statement is based on the observation at Alamogordo, N. Mex.

Representative HOLIFIELD (presiding). This is an area which has very little rainfall. This would not be true in an area that has considerable rainfall, would it?

Dr. LARSON. This area has between 8 and 9 inches annual rainfall.

Representative HOLIFIELD. That is very little in comparison to the average. I imagine we will have close to 50 inches here in Washington.

Dr. LARSON. That is right.

In agricultural areas under cultivation, the distribution of activity is found down to depths of 4 to 8 inches, due to plowing, harrowing, and other farm practices. Laboratory soil leaching experiments using the equivalent of 84 inches of water translocated the surface activity only about a half inch in the soil column.

Representative HOLIFIELD. That is the answer right there, then. Apparently even in areas where you have up to 84 inches, you only displace it about a half inch.

Dr. LARSON. That is right.

Surface-deposited fallout tends to become mechanically trapped in the soil environment. The amount that is redistributed declines with time. Natural disturbance, however, causes material to be redistributed at levels approximating the initial contamination of medium and long-lived fission products.

Particles 44 to 88 microns in diameter contributed an average of 9.7 percent of the total redistributed fallout following Priscilla (balloon) as compared to 21 percent following Smoky (tower) of the Plumbbob test series. Particles less than 44 microns in diameter contributed an average of 85.8 percent following Priscilla compared to 68.3 percent following Smoky.

During the Plumbbob test series, it was found that the gamma radioactive decay measured in the field was similar to the decay of comparable fallout samples measured in the laboratory. Also, the aerosol concentrations were similar following both Priscilla and Smoky despite significant differences in initial contamination.

Forage plants are recontaminated due to redistribution of selected particulates. This provides a continuous source of internal emitters to grazing animals, and a persistent low radiation field which is dependent on the changing proportions of medium to long-lived fission products. During the Teapot and Plumbbob test series, it was found that the principal source of activity found on forage plants is due to particulate fallout in the less than 44 micron size fraction, that is, vegetation within fallout patterns out to 300 miles from Nevada Test Site is a "selective" particulate collector. The number of particles retained by the foliage is dependent upon its characteristics, such as hairs, glands, and other mechanical traps.

The fallout contamination of native plant material persisted through the 18-day period following both Priscilla and Smoky detonations, the only change being that due to radioactive decay.

A negligible fraction of the total contamination of the soil by fallout debris from tower supported detonations was accumulated through the root systems of native forage crops and alfalfa and so on.

One of our principal biological indicators in our fallout studies is the kangaroo rat. This is an example of one of the animals that we have. Another one is the antelope ground squirrel. These animals are abundant in any areas that we would care to work.

During the 1955 test series the concentration of radioiodine 131 in the thyroids of rabbits and other native rodents was found to be a fuction of distance. The maximum concentrations were found at approximately 60 miles. This maximum concentration was a factor of two to seven times higher than that documented at 20 miles or at 160 miles. Twelve months after the Upshot-Knothole series, accumulation of radiostrontium was also found to be a function of distance, with the maximum bone concentrations in rabbits at 130 miles along previously documented fallout patterns.

Six months after the Teapot series in 1955, again, the radiostrontium in the bones of the jackrabbits was found to be a maximum at 130 miles. This was five times higher than either at 30 miles or at 400 miles.

Of the several fission products accumulated in bone, 12.5 to 40 percent was accounted for in terms of radiobarium and radiostrontium by D plus 20 days.

Maximum tissue accumulation of biologically available fission products occurs at locations corresponding to fallout times of H plus 2 to H plus 3 hours. Fission product concentrations then decreased with increasing time of fallout. In the single balloon supported detonation studied, the decrease was constant between locations corresponding to H plus 2 to H plus 12 hours. In tower supported detonations, however, biologically available fission product concentration tended to be uniform over distances corresponding to H plus 5 to H plus 14 hours.

For any given location the relative tissue accumulation of biologically available fission products resulting from Priscilla and Smoky fallout contamination was similar with the maximum values occurring by D plus 7 days.

Biological hot spots were identified geographically in the Boltzmann (78 miles from Ground Zero), Diablo (60 miles from Ground Zero), Smoky (70 miles from Ground Zero), and Shasta (172 miles from Ground Zero) patterns.

This concludes my statement, sir.

Representative HOLIFIELD. Thank you.

Your prepared statement will appear in the record in full.

(The statement referred to follows:)

SUMMARY OF OBSERVATIONS OF DISTRIBUTION, CHARACTERISTICS AND BIOLOGICAL AVAILABILITY OF FALLOUT ORIGINATING FROM CONTINENTAL DETONATIONS

by
K. H. Larson, Chief
Environmental Radiation Division

SUMMARY STATEMENT OF FINDINGS RELATED TO THE TESTING PROGRAM AT NEVADA TEST SITE

During the last decade the Environmental Radiation Division has been involved in progressively intensified programs designed to answer one principal question, viz., 'How much man-made radioactivity distributed in the environment can be tolerated safely by man and his economy?'

The more specific objectives of our effort within this broad context include:

1. Delineation of fallout patterns and their characteristics with respect to particle size through which the mechanics of fallout can be more accurately defined. This, in turn, leads to a comparison of the effects of the yield of device detonated, type of device support, and the relation of the detonated device to ground surface upon the resultant fallout radiation intensity including the residual radioactivity per unit surface area within the fallout pattern.

2. A detailed study of the chemical, physical and radiological characteristics of fallout debris relative to its particle size and occurrence within the fallout pattern.

3. Determination of the biological availability, rate of accumulation, and retention of the fallout debris in various native and domestic plants and animals, as well as the persistence and redistribution of residual contamination in the total environment.

The data to be presented are not directly applicable to the problems resulting from Nuclear War primarily because continental testing has been limited to low yield devices. Further, tests have not been conducted to determine the consequences of fallout from weapons detonated over or on simulated metropolitan complexes. However, the studies that have been made on fallout from variously supported test devices may serve as a basis for establishing certain perimeters for the environmental effects of nuclear war.

FALLOUT PHENOMENOLOGY AND ITS CHARACTERISTICS

Fallout from test devices detonated at Nevada Test Site is governed by many complex variables such as: energy yield; wind structure; the support used for the detonation of devices; ground surface; degree of fireball intersect with ground surface; and mass of inert material or shielding surrounding the device. The data presented the resultant effects and characteristics of fallout from the various detonations studied by this laboratory are summarized in the following statements:

1. Detailed Characteristics of Fallout Patterns: The coordination of aerial survey measurements of fallout patterns with ground survey meter measurements has greatly increased the detail and accuracy of fallout pattern delineation as well as the distances to which fallout patterns can be detected.

By use of aerial survey equipment and techniques as developed by the U. S. Geological Survey, fallout radiation intensities within an area of approximately 10, 000 square miles can be measured in about 12 hours by

one aircraft. Aerial measurements agreed within ± 10 per cent of measurements taken 3 feet above the ground by conventional survey meters. During the Plumbbob Test Series, fallout patterns were routinely measured to distances of 200 to 300 miles from Ground Zero; however, one fallout pattern from a tower-supported detonation was documented as far as 700 miles from the Nevada Test Site with the radiation levels readily detectable at that distance. (See Figures 1, 2, and 3).

The detailed documentation of fallout patterns during the Plumbbob Series (1957) afforded the opportunity to confirm the existence of "hot spots" in most all fallout patterns. Hot spots were first identified in 1948 when the fallout pattern of the Trinity detonation in New Mexico had been outlined in detail.

It is the opinion of the author that terrain features such as mountain ridges create a significant turbulence in the radioactive dust cloud as it moves over the ridge causing an increased amount of fallout to occur on the leeward side. Examples of this are illustrated in the patterns of Shot Diablo (Figure 1) and Shot Smoky (Figure 2) of the Plumbbob Series. Rainouts have also been reported to be responsible for hot spots within 300 miles of NTS. However, the documented hot spots referred to by this Laboratory occurred in areas in which there was no occurrence of precipitation.

While the occurrence of "hot spots" has been associated with prominent terrain features in many cases, data are insufficent to fully explain their mechanism of formation and to permit their prediction. However, the radiation intensity contours of fallout patterns in general have been quite accurately predicted as illustrated by the Weather Bureau prediction and the measured

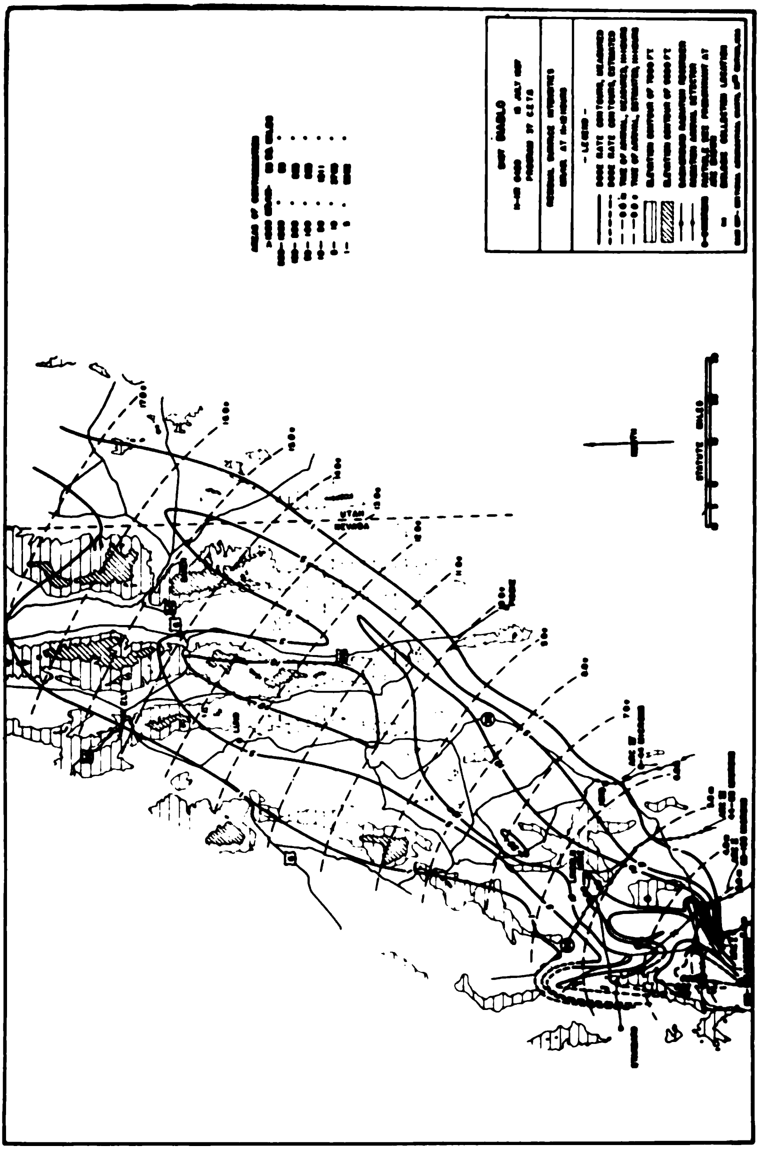

Figure 1

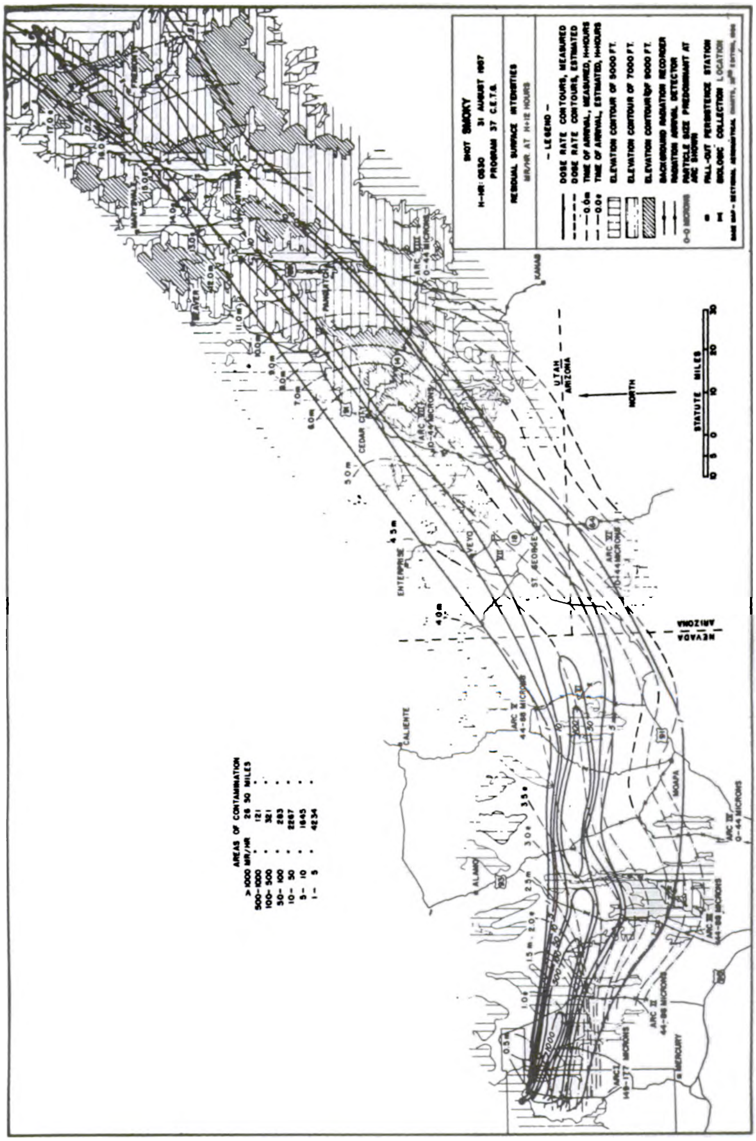
SHOT SMOKY
H-HR: 0530 31 AUGUST 1957
PROGRAM 37 C.E.T.G.
RESIDUAL SURFACE INTENSITIES
MR/HR AT H+12 HOURS
— LEGEND —
DOSE RATE CONTOURS, MEASURED
DOSE RATE CONTOURS, ESTIMATED
TIME OF ARRIVAL, MEASURED, H+HOURS
TIME OF ARRIVAL, ESTIMATED, H+HOURS
ELEVATION CONTOUR OF 5000 FT.
ELEVATION CONTOUR OF 7000 FT.
BACKGROUND RADIATION RECORDER
RADIATION ARRIVAL DETECTOR
FALL-OUT PERSISTENCE STATION
GEOLOGIC COLLECTION LOCATION
STATUTE MILES
NORTH
UTAH
ARIZONA
NEVADA
KANAB
PANGUITCH
CEDAR CITY
ENTERPRISE
VEYO
ST GEORGE
CALIENTE
ALAMO
MOAPA
MERCURY
AREAS OF CONTAMINATION

Figure 2

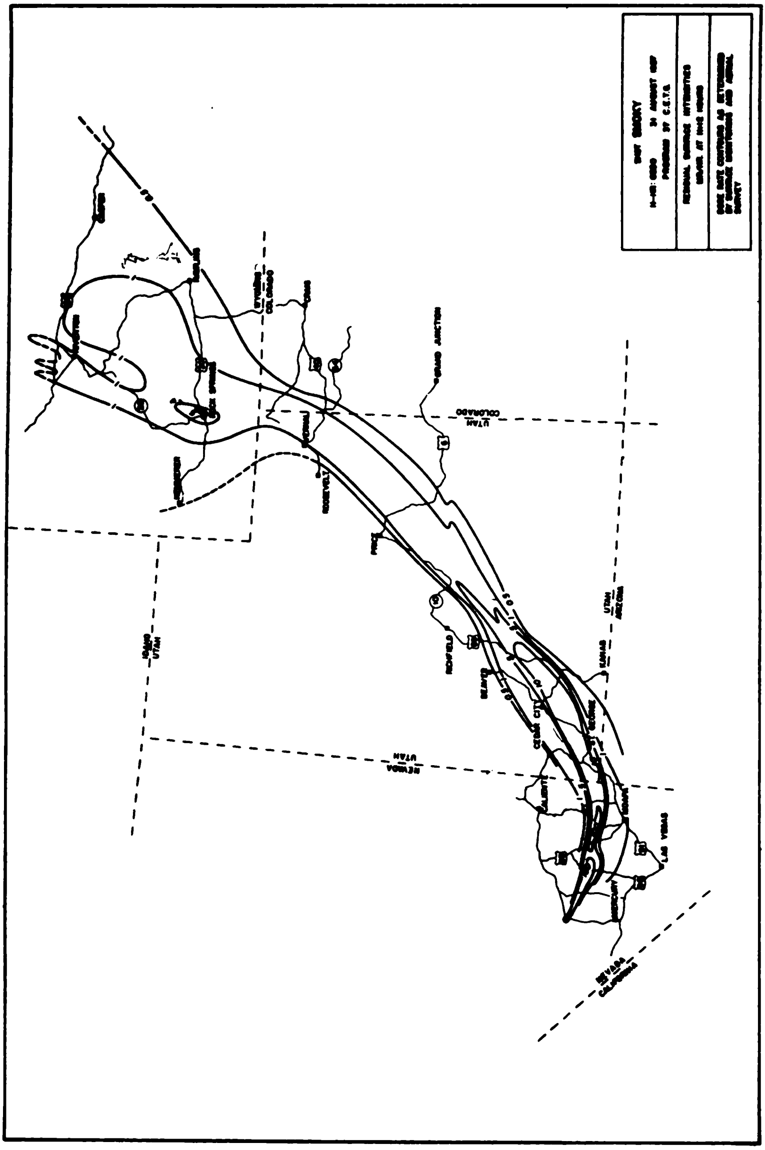
GRAND JUNCTION
UTAH
COLORADO
NEVADA
CALIFORNIA
UTAH
ARIZONA
RICHFIELD
PRICE
ROOSEVELT
CEDAR CITY
LAS VEGAS

Figure 3

pattern of Shot Smoky (Figure 4). It should be noted that quite radical deviations from "idealized" fallout patterns may result from local meteorological conditions; the pattern of Plumbbob Series Shot Wilson (Figure 5) illustrates the effect of widely divergent wind directions of different air strata at the time of detonation.

2. 'Local' Fallout Levels of Radiation: The fallout from aerial bursts have not been detectable by conventional ground survey methods within 200 miles of Ground Zero. Two test devices detonated from balloons at 1500 feet without the fireball intersecting the soil surface deposited less than 0.2 per cent of the theoretical fallout activity(1). The area measured is defined by the 1 mr/hr radiation intensity contour (at H + 12 hrs) and between the distance of 1 mile from Ground Zero and the distance corresponding to a fallout time of H + 12 hrs. To illustrate the effect of the intersection of fireball, a balloon-supported shot which did intersect the soil surface deposited 2.12 per cent of the theoretical fallout. However, fallout originating from test devices mounted on steel towers whose fireball in some cases intersected the soil surface and in other cases did not, deposited 6.7 to 24.5 per cent of the theoretical fallout activity within the same area limits stated above.

3. Particle Size Distributions in Fallout Patterns: The size of fallout particles decreases with distance from Ground Zero. Also, the size of fallout particles decreases with the lateral distance from the line of maximum radiation intensity along a fallout pattern or midline of fallout. The relative

(1) The theoretical fallout is calculated on the basis of 300 gamma megacuries at H + 1 hr per KT yield.

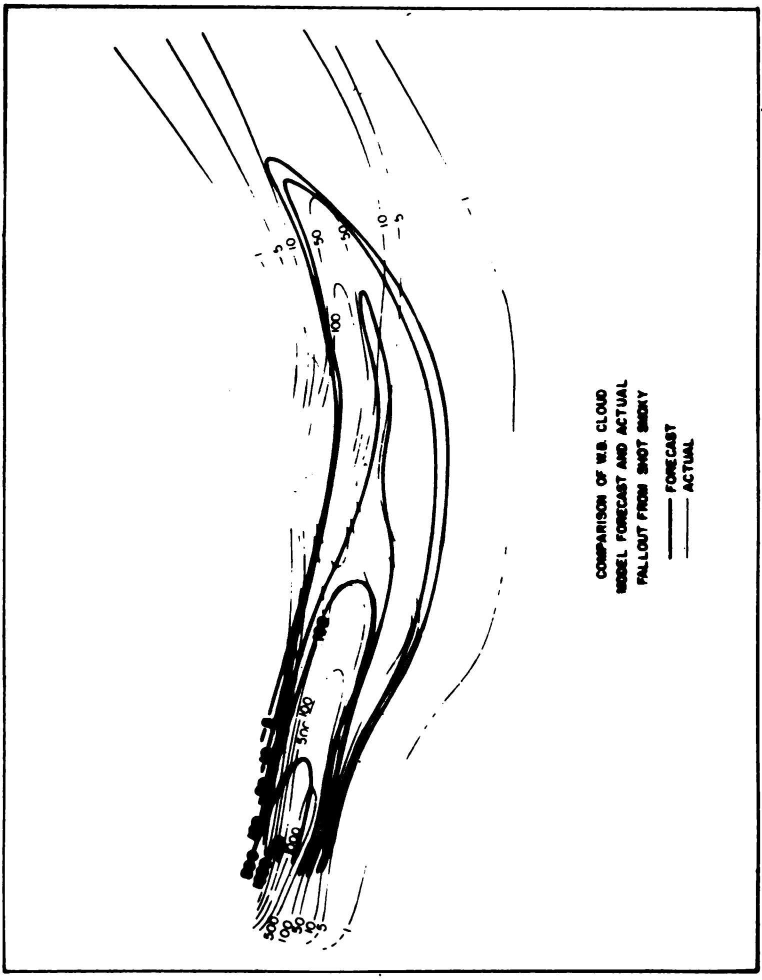

Figure 4

43338 O—59——52

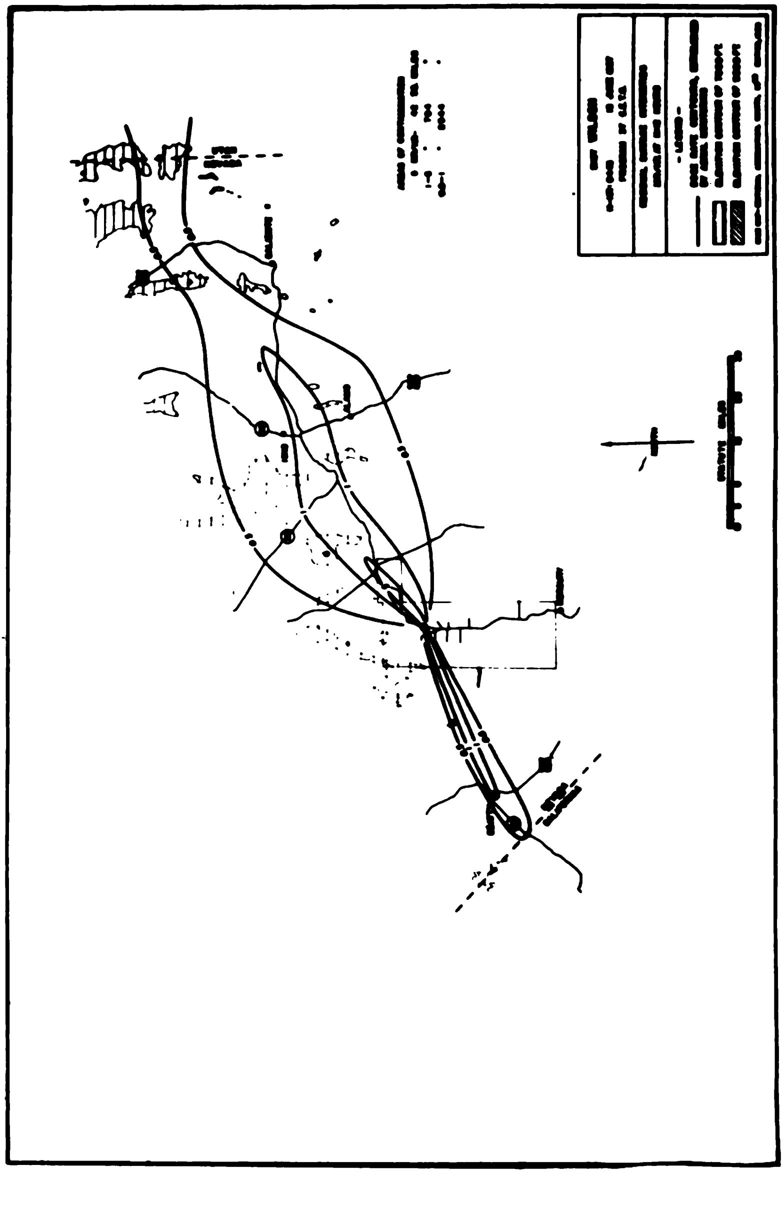

Figure 5

amount of radioactivity associated with particle sizes less than 44 micron was increased by decreasing the mass of support and cab materials. Therefore, the amount of fallout occurring at greater distances from Ground Zero was also increased.

It was found that vegetation in the environs of Nevada Test Site during the Teapot Series (1955) retained predominately less than 44 micron fallout particles. Therefore, this size range has been emphasized in our recent studies.

Within the limits of 1 mile from Ground Zero and to a distance corresponding to H + 12 hr fallout time, test devices detonated on 500- and 700-foot towers had approximately 30 per cent of the fallout activity associated with particles less than 44 microns in diameter. However, a test device of comparable yield (KT) mounted on a 700-foot balloon had 70 per cent of the fallout activity associated with the same size fraction.

On the average, 38 to 50 per cent of the radioactivity contained in the less than 44 micron-diameter fallout samples from tower-mounted detonations was associated with the less than 5 micron-diameter particles and 51 to 83 per cent in the case of fallout samples from balloon mounted detonations. Various percentage contributions of less than 5 micron-diameter fallout particles were observed at virtually all sampling locations for both tower and balloon-mounted detonations.

4. Solubility of Fallout Material: Solubility is one of the most important properties of fallout with respect to the 'internal emitter' problem in biological systems. As indices of biological availability, we arbitrarily use the

solubility of fallout material in water and 0.1 N hydrochloric acid (HCl).

The fallout material from balloon-supported detonations was more soluble in both water and acid than that produced by other types of detonation. The solubility of fallout from tower-supported detonations increased with decreasing particle size. However, in the case of balloon-supported detonations, the smaller particles were somewhat less soluble than larger particles.

	Fallout Material from: Tower shots	Fallout Material from: Balloon shots
Water solubility expressed as per cent total beta activity:		
greater than 44 micron fraction	< 1%	31%
less than 44 micron fraction	< 2	14
0.1 N HCl solubility expressed as per cent of total beta activity:		
greater than 44 micron fraction	5	> 90
less than 44 micron fraction	14 to 36	> 60

It should be noted that fallout from the underground shot, Jangle Series (1951) had a solubility greater than tower-mounted detonations but less than balloon-mounted detonations for the particle range of less than 44 microns. It was 5.4 per cent soluble in water and 25 per cent soluble in 0.1 N HCl.

5. Radiochemical Properties of Fallout Materials: Fallout particles less than 44 microns had greater percentages of radiostrontium and radio-

ruthenium at 30 days after detonation than larger particle sizes. The percentages of radiostrontium and radioruthenium in balloon-mounted detonation fallout were several times higher than in corresponding particle sizes from tower-mounted detonations. The reverse was true of radiozirconium. Radiobarium, radiocerium, and radioyttrium varied to a lesser degree between tower and balloon-shot fallout. Strontium^{90} averaged 2.7 per cent of total radiostrontium at D + 30 days fallout originating from detonations mounted on towers.

The distribution, as of D + 30 days, of radioisotopes of Ba, Ce, Ru, Sr, Y, and Zr with respect to different particle sizes of fallout from tower and balloon-mounted detonations is illustrated in Figure 6. The average radioactivity values expressed as per cent of the total activity due to the primary contributing isotope(s) at D + 30 days are summarized below:

	Average Per Cent of Activity at D + 30 Days		
Isotope	Tower	Balloon	Theoretical U235 Fission Products(1)
Ba-140	13.7	17.9	10.49
Ce-141, 144	17.6	14.3	13.10
Ru-103, 106	2.6	9.2	5.99
Sr-89	1.83	4.3	6.00
Sr-90	0.05	-	0.08
Y-91	10.4	14.0	7.74
Zr-95	7.8	3.93	8.13

(1) Bolles and Balleau, USNRDL-456.

Comparison of Radioelement Percentages of Different Particle Size Fractions of Tower and Balloon Shot Fallout

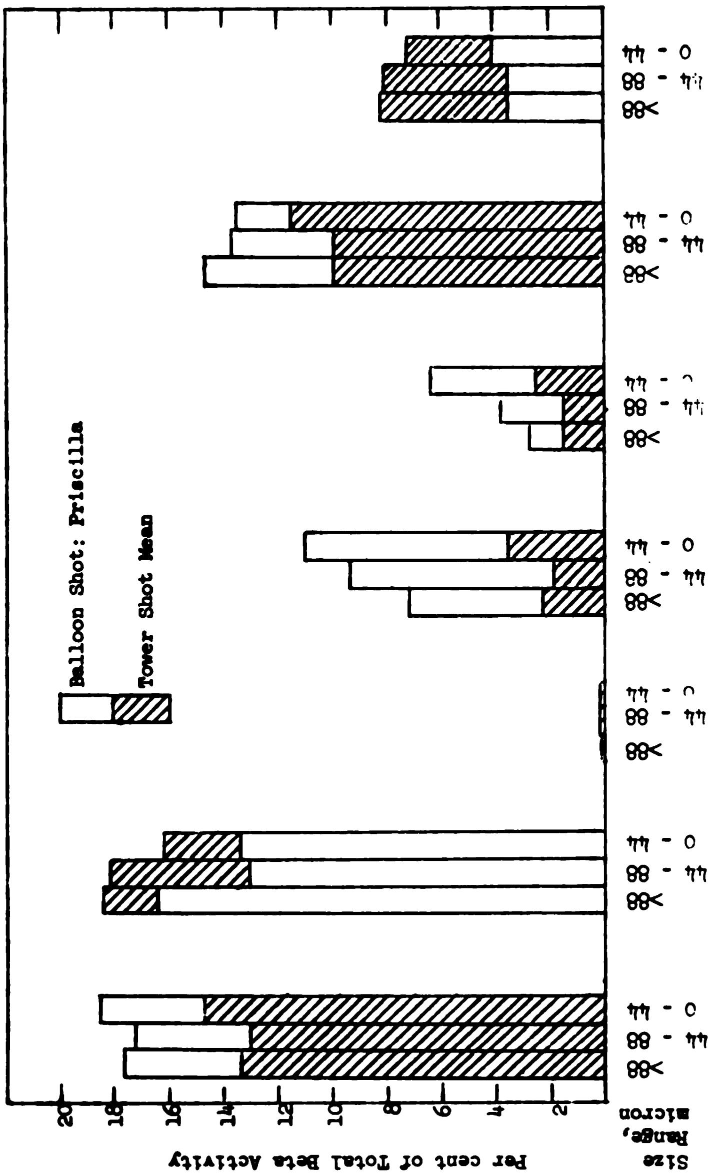

Figure 6

6. Comparison of Chemical Properities of Fallout From Two Detonations: A comparison of fallout from a balloon-mounted and a tower-mounted detonation having similar KT yield and the same detonation height of 700 feet indicated that over the distance having a 1- to 15-hr fallout time period, the amounts of water-soluble radiobarium and radiostrontium deposited by the less than 44 micron fraction of each detonation were similar despite relatively large differences in the level of the total radioactivity in this size fraction.

The widespread distribution of the less than 44 micron fallout fraction from all types of devices detonated at the Nevada Test Site indicates that this size fraction is probably the most significant with respect to total area of contamination. Assuming that the soluble fractions of fallout reflect the same radioelement percentages as the original fallout, the application of solubility percentages to radioelement percentages yields the percentages of the various radioelements in 0.1 N HCl and water-soluble extracts. Based on such calculations, the relative amounts of the several radioelements in the soluble fractions of equal amounts of less than 44 micron fallout from a tower- and a balloon-mounted detonation of similar yield and height of detonation appear in Figure 7. The deposition of less than 44 micron fallout from the tower-mounted detonation, however, considerably exceeded that of the balloon-mounted detonation at different fallout times from 1 to 15 hrs (Figure 8).

The application of soluble radioelement percentages to measured and integrated less than 44 micron radioactivities of the two detonations gives an estimate of the relative amounts of the various radioelements at different

Calculated Priscilla/Smoky D + 30 Day Radioelement Ratios in Untreated, Acid-soluble, and Water-soluble Fractions of 0 - 44 micron Fallout

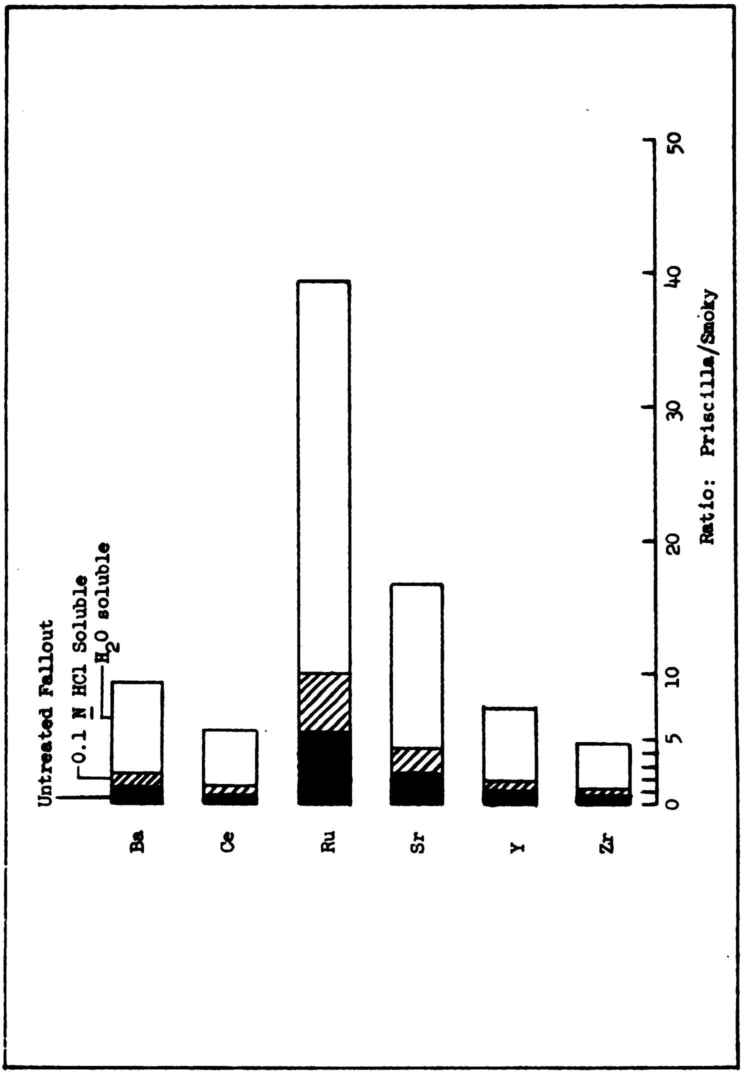

Figure 7

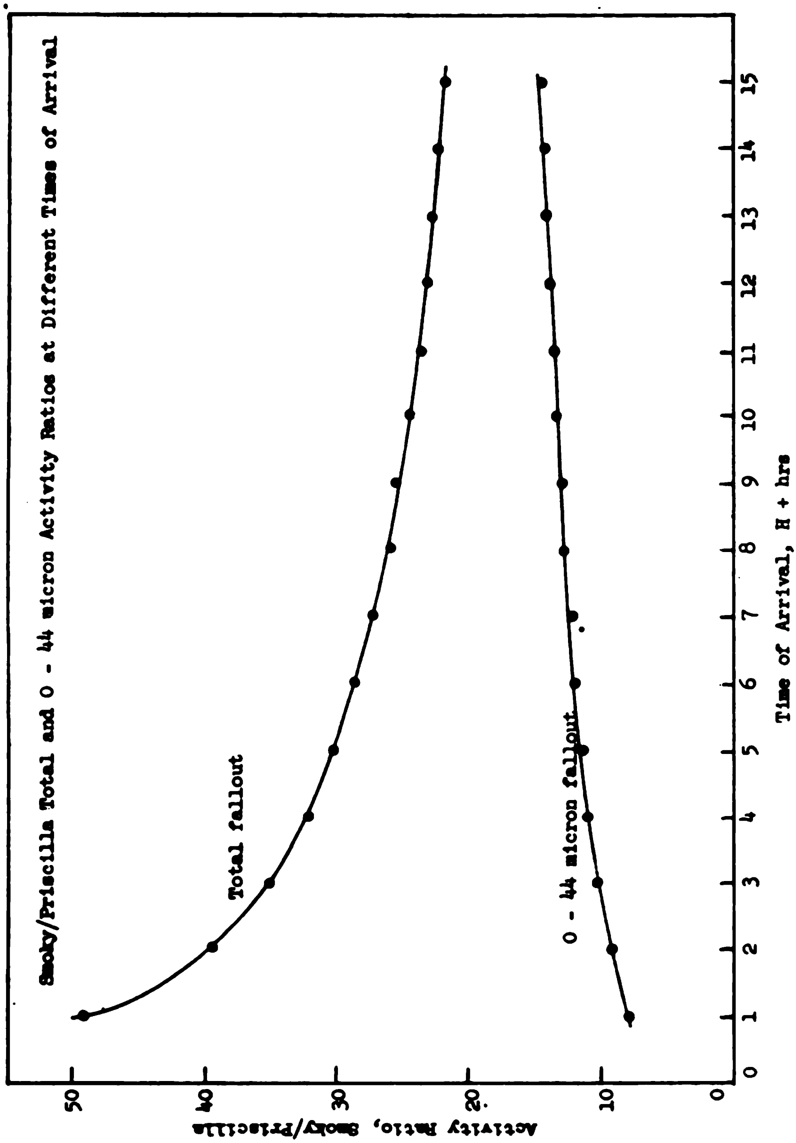
Smoky/Priscilla Total and 0 - 44 micron Activity Ratios at Different Times of Arrival
Total fallout
0 - 44 micron fallout
Activity Ratio, Smoky/Priscilla
0
10
20
30
40
50
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Time of Arrival, H + hrs

Figure 8

fallout times. As examples, the relative amounts of total acid-soluble and water-soluble radiobarium and radiostrontium derived from the less than 44 micron size fraction deposited by the two detonations at various fallout times appear in Figures 9 and 10. While the amounts of total and acid-soluble radiobarium and radiostrontium deposited by less than 44 micron fallout from the tower-mounted detonation are higher over the 1- to 15-hr fallout period, the amounts of water-soluble radiobarium and radiostrontium are similar.

7. Decay of Fallout Radioactivity: Fallout materials from a specific detonation had similar beta decay curves regardless of particle size and time of fallout. Beta decay curves of most detonations approximate the $T^{-1.2}$ decay relationship over a period of H + 12 to H + 6,000 hrs. However, slopes of the order of $T^{-1.4}$ occurred from H + 6,000 to H + 10,000 hrs.

Decay curves of the gamma emission rate were different from those of beta decay for fallout materials from a specific detonation. Gamma decay curves of fallout from different shots were generally similar, but more variable than corresponding beta decay curves.

Estimates of dosage in fallout areas have generally been based, in part, on a decline of dose-rate (mr/hr) with time according to the $T^{-1.2}$ relationship. A dose-rate decline with time according to the Plumbbob gamma decay (PGD) curve yields calculated doses which are 1.5 to 2 times greater than those calculated by the $T^{-1.2}$ relationship for different fallout times to approximately 400 days after shot (see below):

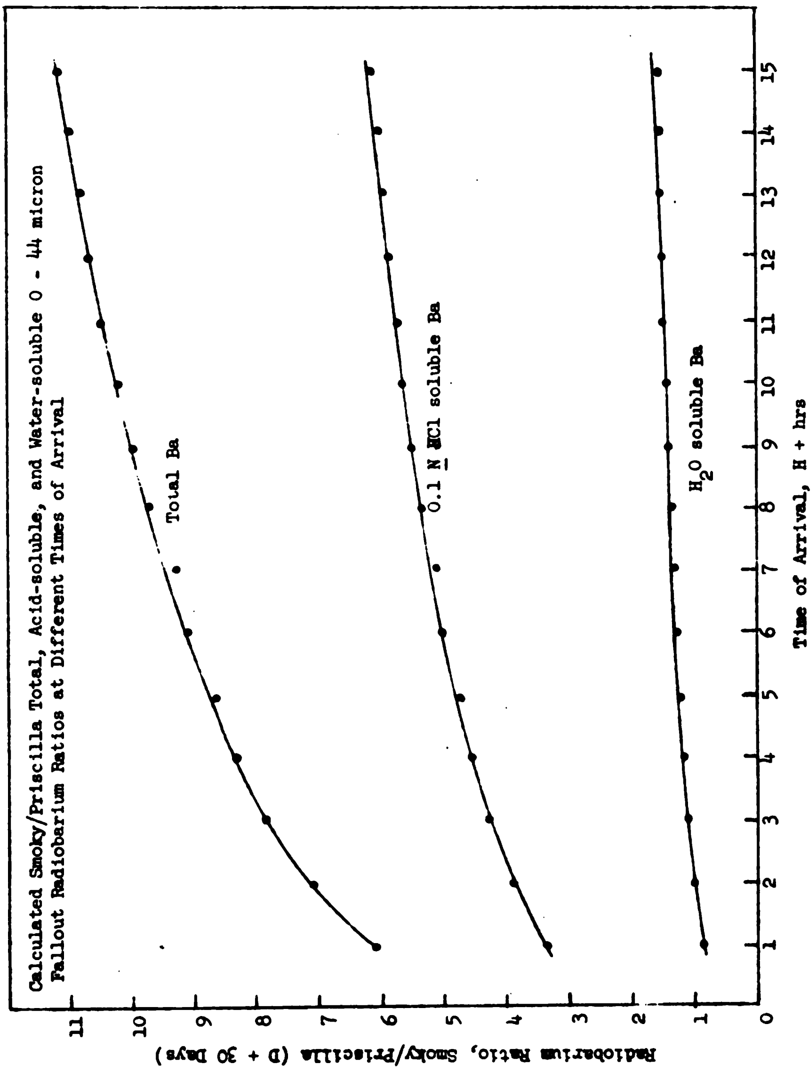
Calculated Smoky/Priscilla Total, Acid-soluble, and Water-soluble 0 - 44 micron
Fallout Radiobarium Ratios at Different Times of Arrival
Total Ba
0.1 N HCl soluble Ba
H_2O soluble Ba
Time of Arrival, H + hrs
Radiobarium Ratio, Smoky/Priscilla (D + 30 Days)

Figure 9

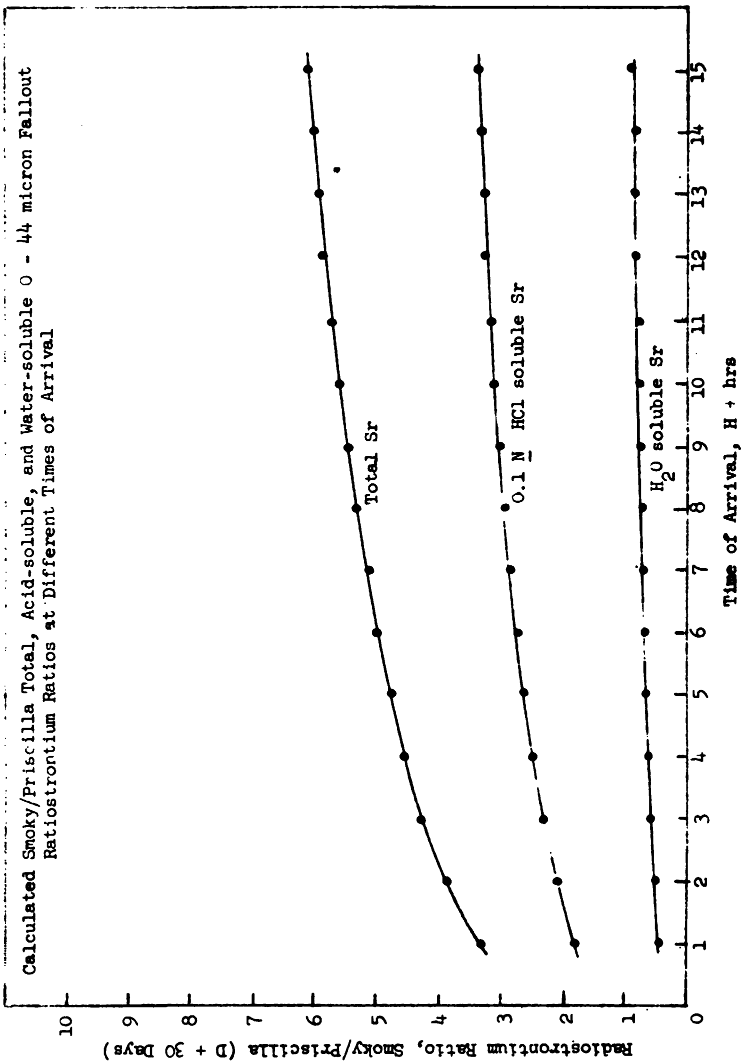
Calculated Smoky/Priscilla Total, Acid-soluble, and Water-soluble 0 - 44 micron Fallout
Radiostrontium Ratios at Different Times of Arrival
Total Sr
0.1 N HCl soluble Sr
H_2O soluble Sr
Radiostrontium Ratio, Smoky/Priscilla (D + 30 Days)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time of Arrival, H + hrs

Figure 10

Comparison of Dose to 10,000 hrs Calculated on the Basis of Plumbbob Gamma Decay (Curve and $T^{-1.2}$ Relationship(using 100 mr/hr at Time of Arrival for example)

Time of Arrival	Dose to 10,000 hrs using PGD curve	Dose to 10,000 hrs using $T^{-1.2}$	Ratio of Plumbbob Dose to $T^{-1.2}$ Dose
H + 2 hr	1,638 mr	818 mr	2.00
H + 4	2,635	1,582	1.67
H + 6	3,993	2,319	1.72
H + 8	4,979	3,041	1.64
H + 10	5,917	3,744	1.58
H + 12	6,679	4,437	1.51

8. Deposition of Radiostrontium in Areas Adjacent to Nevada Test Site: A balloon-mounted detonation, whose fireball intersected the soil surface, deposited approximately 0.13 per cent of the total amount of Sr^{89} produced(1) within the area limits defined previously (Sec. 2). Two balloon-mounted detonations, whose fireballs did not intersect the soil surface, deposited 0.004 and 0.008 per cent within the above perimeters of the total amount of Sr^{89} produced. Tower-mounted detonations deposited from 0.5 to 2 per cent of the Sr^{89} produced and from 1.6 to 7.2 per cent of the total amount of Sr^{90} produced(1).

Calculations were based on the results of Sr^{89} and Sr^{90} analyses of fallout samples and integrated fallout radiation intensities converted to curies by ratios of $\mu c/ft^2$ and mr/hr. The analysis of balloon shot samples for Sr^{90} was not performed.

(1) The theoretical potential Sr^{89} and Sr^{90} fallout is based on the production of 1 gram or 27,700 curies of Sr^{89} and 1.14 gram or 146 curies of Sr^{90} per KT yield at H + 1 hr.

The tower shot percentage deposition of Sr^{89} is less than that of Sr^{90} out to distances corresponding to H + 12 hr fallout time. This is due to relatively low percentages of Sr^{89} in larger particle sizes which generally represent the majority of the fallout activity in areas close to Ground Zero. This fractionation of Sr^{89} and Sr^{90} with respect to particle size may be predicted on the basis of the different half-lives of their noble gas precursors, Kr^{89} and Kr^{90}, respectively, and the rate of particle formation.

BIOLOGICAL AVAILABILITY AS RELATED TO THE FATE AND PERSISTENCE OF FALLOUT AS MEASURED AT VARIOUS LOCATIONS WITHIN FALLOUT PATTERNS UP TO 400 MILES FROM NEVADA TEST SITE

In undisturbed areas the radioactive debris from fallout is confined to the surface two inches of the soil profile even after nine years following fallout contamination (Trinity Areas, New Mexico). In agricultural areas under cultivation, the distribution of activity is found down to depths of four to eight inches due to plowing, harrowing, etc. Soil leaching laboratory experiments using the equivalent of 84 inches of water translocated the surface activity only about 0.5 inch into the soil column.

Surface-deposited fallout tends to become mechanically trapped in the soil environment. The amount that is redistributed declines with time. Natural disturbance, however, causes material to be redistributed at levels approximating the initial contamination of medium- and long-lived fission products.

Particles 44 - 88 microns in diameter contributed an average of 9.7 per cent of the total redistributed fallout following Priscilla (balloon) as compared to 21.0 per cent following Smoky (tower) of the Plumbbob Test Series. Particles less than 44 microns in diameter contributed an average of 85.8 per cent following Priscilla compared to 68.3 per cent following Smoky.

During the Plumbbob Test Series, it was found that the gamma radioactive decay measured in the field was similar to the decay of comparable fallout samples measured in the laboratory. Also, the aerosol concentrations were similar following both Priscilla and Smoky despite significant differences in initial contamination.

Forage plants are recontaminated due to redistribution of selected particulates. This provides a continuous source of internal emitters to grazing animals, and a persistent low radiation field which is dependent on the changing proportions of medium- to long-lived fission products. During the Teapot and Plumbbob Test Series, it was found that the principal source of activity found on forage plants is due to particulate fallout in the less than 44 micron size fraction, i.e., vegetation within fallout patterns out to 300 miles from Nevada Test Site is a 'selective' particulate collector. The number of particles retained by the foliage is dependent upon its characteristics such as hairs, glands, and other mechanical traps. Up to 21.6 per cent of the contamination on washed leaves was soluble in 0.1 N HCl, which suggests that a similar percentage of the fallout material ingested would be available to animals.

The fallout contamination of native plant material persisted through the 18-day period following both Priscilla and Smoky detonations, the only change being that due to radioactive decay.

A negligible fraction of the total contamination of the soil by fallout debris from tower-supported detonations was accumulated through the root systems of active forage crops and alfalfa (within 300 miles of the Nevada Test Site).

During the 1955 Test Series the concentration of radioiodine I^{131} in the thyroids of rabbits and other native rodents was found to be a function of distance. The maximum concentrations were found at approximately 60 miles. This maximum concentration was a factor of 2 to 7 times higher than that documented at 20 miles or at 160 miles. Twelve months after the Upshot-Knothole Series, and six months after the Teapot Series, accumulation of radiostrontium was also found to be a function of distance, with the maximum bone concentrations in rabbits at 130 miles along previously documented fallout patterns.

Between 82 and 87 per cent of the total radioactivity found in the thyroid tissue of the native rodents at H + 72 hrs consisted of 17 - 20 per cent as $iodine^{131}$ and 65 to 67 per cent as $iodine^{133}$. The maximum accumulation occurred at approximately D + 14 days with samples taken at D + 20 days containing only $iodine^{131}$. Of the several fission products (Sr^{89-90}, Y^{91}, Ce^{144}, Cs^{137}, and Ba^{140}) accumulated in bone, 12.5 to 40.0 per cent was accounted for in terms of radiobarium and radiostrontium by D + 20 days.

Maximum tissue accumulation of biologically available fission products occurs at locations corresponding to fallout times of H + 2 to H + 3 hrs. Fission product concentrations then decreased with increasing time of fallout. In the single balloon-supported detonation studied, the decrease was constant between locations corresponding to H + 2 to H + 12 hrs. In tower-supported detonations, however, biologically available fission product concentration tended to be uniform over distances corresponding to H + 5 to H + 14 hrs.

For any given location the relative tissue accumulation of biologically available fission products resulting from Priscilla and Smoky fallout contamination was similar with the maximum values occurring by D + 7 days.

Biological 'hot spots' were identified geographically in the Boltzmann (78 miles from Ground Zero). Diablo (60 miles from Ground Zero), Smoky (70 miles from Ground Zero), and Shasta (172 miles from Ground Zero) patterns.

In the laboratory, the rate of radioactive decay of isolated tissue samples, collected from the field at the beginning of any particular study, the decline of radioactive content of tissues serially sampled from the field population, and the rate of radioactive decay of fallout in the environment are similar for samples of skin, GI tract, and muscle. Liver and kidney tissue from the population and individuals are similar in decay characteristics but deviate markedly from the rate of radioactive decay of fallout in the environment. These relationships are not apparent for bone which reflects the build-up and retention of specific isotopes.

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SR^{90} CONTAMINATION LEVELS IN NEVADA AND UTAH SOILS

Strontium^{90} levels of surface 0 - 1 inch soil samples collected in Nevada and Utah in August, 1958, ranged from 31.9 to 142 mc/sq mile in virgin areas near known fallout midlines. From 7.5 to 22.7 mc/sq mile were found in agricultural areas and did not coincide with fallout midlines.

The Sr^{90} contamination levels in agricultural 0 - 1 inch surface soil samples are lower than those of virgin area samples (Table 1) probably as a result of both lesser amounts of fallout from Nevada Test Site activities and subsequent cultivation of the soil. The observed surface levels in agricultural areas are similar to those reported in other areas of the country.

SOIL-PLANT FACTORS EXPERIMENTALLY DETERMINED WHICH AFFECT SR^{90} AND CS^{137} ACCUMULATION IN CROPS

Several soil and plant factors influence the availability and accumulation of fission products in plants. Laboratory and greenhouse studies indicate that radiostrontium is most readily accumulated by crop plants from artificially contaminated soils. Only very small amounts of Y^{91}, Ru^{106}, Cs^{137}, and Ce^{144} were accumulated.

In a short time experiment (21 days), the addition of non-composted organic matter to soils reduced Sr^{90} uptake by barley seedlings. The application of undecomposed organic matter at the levels equivalent to 10, 20, 50, and 100 tons per acre reduced the uptake of Sr^{90} 12, 30, 50, and 75 per cent, respectively. The influence of the organic matter applied was related to its effect on the soil microbial population and to the change

Table 1

Sr90 Levels by Fusion Analysis at Eleven Selected Areas in Nevada and Utah

Date of Collection, August, 1958

Area	Location	Sr90 Activity (0 - 1" Depth) mc/sq mi	Sr90 Activity (0 - 1" Depth) μμc/g Ca
Cultivated Agricultural Areas			
Alamo, Nevada	1 mi S	21.3	6.8
Moapa, Nevada	7.7 mi NW	16.3	2.5
Riverside, Nevada	0.4 mi S	22.7	9.6
St. George, Utah	1 mi SE	14.4	4.5
Hurricane, Utah	1 mi SW	12.4	3.5
Enterprise, Utah	0.7 mi N	7.46	8.6
Cedar City, Utah	2 mi SW of Enoch	16.7	4.6
Vernal, Utah	4 mi S	13.8	8.7
Virgin Undisturbed Area, Fallout Midline Locations			
Moapa, Nevada	8 mi N	142.[illegible]	38.3
Elgin, Nevada	3.8 mi SW	114	140
St. George, Utah	9 mi N	45.6	406
Enterprise, Utah	9 mi N	41.2	51.2
Panguitch, Utah	City limit, NW corner	31.9	14.9
Sunnyside, Utah	3.1 mi S of Columbia, Utah	67.2	202

in the chemical composition of the soils as the organic matter decomposed.

The addition of lime ($CaCO_3$) and gypsum ($CaSO_4$) to acidic soils low in native Ca reduced Sr^{90} uptake by plants. Greatest inhibition occurred at treatment levels equivalent to from 2 to 5 tons per acre. At these levels $CaCO_3$ reduced Sr^{90} uptake about 60 per cent; $CaSO_4$ caused an 80 per cent reduction. These Ca amendments to the soil had little or no influence on the uptake of Sr^{90} from neutral and alkaline soils.

The uptake of Cs^{137} occurring as a contaminant increased as the K concentration in the soil was reduced by prolonged cropping. The addition of K to contaminated soils low in potassium content reduced the uptake of Cs^{137} by plants.

These radioecological studies have clearly revealed that (1) biological effect (or hazard) cannot be realistically assessed on the basis of measurement of only the gamma radiation field. Fission products from radioactive debris produced by man can be assimilated by animals with the maximum degree of accumulation not necessarily near the source of the nuclear reaction. Further, within a distance of 400 miles from the Nevada Test Site, the plant foliage is a selective particle collector. There has been no significant accumulation of activity through the root system. (2) Biological availability of fallout debris is strongly influenced by the conditions of contamination and by the physical and chemical nature of the contaminating material and its interaction with environmental factors. (3) Within 200 miles from the Nevada Test Site Sr^{89} and Sr^{90} are estimated to be less than 10 per cent of the total theoretical Sr^{89} and Sr^{90} generated by all detonations at the Nevada Test Site since the Ranger Test Series.

Representative HOLIFIELD. Are there any questions of Dr. Larson?

Representative HOSMER. Yes; Dr. Larson, your prepared statement is in rather direct contradiction to the evidence we had a couple of days ago. I was trying to find it, but I could not find it in the record.

In your statement you say:

It is the opinion of the author that terrain features such as mountain ridges create a significant turbulence in the radioactive dust cloud as it moves over the ridge causing an increased amount of fallout to occur on the leeward side.

We had a witness tell us that mountain ranges made no difference whatsoever except in cases of the wind coming on the slant. Can you explain why two gentlemen so well versed in this field could disagree so fully?

Dr. LARSON. I do not know if we are in disagreement, sir. It is a matter that we have not been able to pin down. My opinion is, based on the observations that we have made now of some 18 different patterns, that if you have any significant wind velocity, as the cloud moves over a ridge of several thousand feet, you are likely to find a hot spot on the other side, the lee side.

Representative HOSMER. Well, now, when the snow is coming down, they pile up on the windward side of the ridge, do they not?

Dr. LARSON. We have not found this evidenced with respect to these particles or the fallout material.

Representative HOSMER. Do you think the size of the particle has a bearing on it?

Dr. LARSON. After they get beyond a few miles, something less than 5 miles, for example, the heavy material that might be influenced, as you described, from then on in we have particles that are usually less than 100 microns. And the airflow will govern this to a large extent. And it is my belief that as we get more data, if we are able to, we will find the mechanism for this eventually, for this observation that we have made.

Representative HOSMER. It would appear to be a relatively simple thing to experimentally ascertain. Is it just that because of the semi-inconsequentialness of it, the work has not been done?

Dr. LARSON. We have not had the time yet, sir.

Representative HOSMER. The answer, then, would be yes, would it not? You are taking first things first?

Dr. LARSON. That is right.

Representative HOSMER. Thank you.

Representative HOLIFIELD. Dr. John N. Wolfe, Chief of the Environmental Sciences Branch, Division of Biology and Medicine, U.S. Atomic Energy Commission, will present testimony on the long-time ecological effects of nuclear war.

Dr. Wolfe has had considerable experience in the field of ecology both in exploration and teaching.

You may proceed, sir.

STATEMENT OF JOHN N. WOLFE,[1] CHIEF, ENVIRONMENTAL SCIENCES BRANCH, DIVISION OF BIOLOGY AND MEDICINE, U.S. ATOMIC ENERGY COMMISSION

Dr. WOLFE. Mr. Chairman and members of the committee, it is a rather considerable privilege to appear before your group, because I may be perhaps the only ecologist that has ever been in here, although you have received a considerable amount of ecological testimony from time to time.

Representative DURHAM. I think you are the first.

Dr. WOLFE. I do not know whether any of the other witnesses would want to be called ecologists.

What I have to talk about is the long-time effects of nuclear war. And ecologically, this is very difficult to assess.

In the first place, I am talking in terms of broad general landscape processes, such as erosion, fire, and all the other processes that go to make the landscape. In the second place, I am talking about things for which we have no experimental data.

Our detonations, first of all, were on the desert, and if I remember the map not many of your devices will be dropped on the desert. In the second place, where we have the opportunity to study the biology of a region or an area most significantly from a human relations viewpoint there have been no nuclear detonations, that is, in any humid region, such as the deciduous forest region of eastern North America.

In the third place, there has never been an opportunity to totally survey, from a biological point of view, a landscape or a seascape prior to a detonation.

Our evaluations have had, therefore, to come from the studies afterward, not knowing what ground zero is biologically.

Therefore, it is only possible to paint a picture in broad strokes. Perhaps it is only possible to raise questions that would put us in some perspective as to the kinds of things that we would be concerned with.

Vicissitudes of the environment and long-time processes such as mountain building, erosion, emergence, and submergence of the land, fire, climatic fluctuations, and glaciation, have all played a role in the history of the biota of this continent. Included in that list would be vulcanisms (volcanoes). And life has managed to survive.

It therefore would appear to me that even in any kind of nuclear war, there would be survival of life. And what the condition of man would be, I am not able to predict, and leave that for others. But there would not be complete obliteration. Even in local areas, there would be readvancement of living things.

I think that even the radiation effects which have been described here by more competent people than I am in this field, as in the past, would perhaps result in the survival of the fittest, the elimination of

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the unfit (biotypes); that is, organisms with genetic constitutions that would enable them to live in the new environment would be the survivors.

However, omitting consideration of radiation, widespread damage due to the thermal and blast components of the bomb would occur in many kinds of biotic systems.

And now I talk not in terms of fire alone, although I think fire in the dry season of mid-October would spread over enormous areas of the dry western coniferous forests and in the grasslands, with concomitant destruction of natural living resources and their habitats.

Now the cost in fire alone is a single factor. The chain of events that fire triggers represents the long-time effects.

Let me give an illustration, very briefly, of what might happen if the balance is upset in an Arctic region. I step outside of the smaller States to the south, because this is a simple illustration of the kind of thing that I am trying to describe, and which is almost indescribable in Temperate Zones.

In the Arctic, the sole support of animal life commences with the algae of the sea, the microscopic green plants that are the producers of food. These in turn are eaten or absorbed by smaller animals, which in turn are eaten by larger animals, which in turn form the food for fish, which in turn form the food for the walrus, the seal, the polar bear, which in turn is the substance, the food, and the shelter, of the economy of the Eskimo.

Any place in that chain that is broken will result in the elimination of the Eskimo from that invironment. He has no alternative economy.

A more complex situation exists in Temperate Zones, and a still more complex situation exists in the Tropics, but, you see, they all operate on the same basic principle.

It is likely, in my opinion, that these fires would go unchecked until quenched by the winter snows.

Representative HOSMER. Doctor, to what areas are you directing this?

Dr. WOLFE. I am speaking to those areas untouched thus far. The area outside of the 25-mile limit of destruction by fire and blast.

Representative HOSMER. But your illustration in Alaska would not be in the chain of events from this attack here. I just want to make it clear.

Dr. WOLFE. I use that to illustrate a principle, the food chain principle.

Representative HOSMER. Do you feel that the forests of the entire West would be subject to fires from this attack?

Dr. WOLFE. I think in local areas such as the Los Angeles watershed there would be complete destruction. In other regions there would be a mosaic of fire areas, ranging in extent from those that are small and what we would call local to areas of thousand or more square miles in area.

Representative HOSMER. They would in and of themselves follow the same pattern as a fire caused by——

Dr. WOLFE. A cigarette butt or a campfire.

Representative HOSMER. That is right. And instead of one valley being subject to the fire, there might be a number of valleys and ridges simultaneously?

Dr. WOLFE. Even with an expertly controlled fire, we still have 5,000 square miles of fire every year in natural forests. And I think this could be multiplied by perhaps a hundred or maybe someone else would say 200 or even 500 at this season of the year.

Representative HOSMER. But even in, say, Los Angeles area, of which you spoke, this kind of fire would be localized to that area. I mean, it would not proceed on to Nevada or some place else like that.

Dr. WOLFE. I think there would be a barrier there wherever there is desert. Not much of the desert gets fired from the test shots. I think it would be confined to the dryer forest types of the Rockies and the Northwest and the Pacific coast, and in the east the dryer forest types, such as the oak and the pine, and the Southeast coastal plains, and the south gulf coastal plain, where two-thirds of our forest loss by fire each year occurs, would be pretty well burned.

Representative HOSMER. Let us take the area—I think we jumped from San Francisco up to Portland on this hypothetical attack. So we have parts of Oregon and all of northern California, in which there would not be this kind of fire you mentioned.

Dr. WOLFE. I do not think the fires in the Douglas-fir forest of the Olympic Peninsula would cause as much damage as the damage that would be caused in the dry forest types, the chaparral, which is not forest, but woodland, and the lower forests below Engleman spruce and those species that occur just below timberline. They would be snow covered at that time.

Representative HOSMER. They would be what?

Dr. WOLFE. Snow covered.

Representative HOSMER. What I am trying to get at is that you would not get a fire over in the Lake Tahoe area in California, let us say, as a consequence of a nuclear detonation on San Francisco locally.

Dr. WOLFE. No; I do not think that is where the fire would come, unless it were caused by wind blowing debris that far, which is not very likely.

Representative HOLIFIELD. You would be faced, however, with a lack of firefighting equipment and a loss of personnel to handle that, because more emergent needs would demand the attention of the remaining people. The chances would be that where we ordinarily have a great firefighting system out in our States, such as firefighting equipment as they might have might be drawn into the villages and towns for use if there was any available.

Dr. WOLFE. I talked to the Forest Service an hour or so ago, and while they said they were well equipped to fight fire, they would probably be called into duty somewhere else in the event of nuclear war.

Representative DURHAM. The picture you paint of the Eskimo involves the question of concentration. It would take 10 times or 20 times what you would get from the Eskimo. And you would get the same results as to the end survival of the human being.

Dr. WOLFE. That is the point I wanted to make.

Representative DURHAM. It is not a question of so much ability to fight the fire. It is the question of how much concentration we get over the areas where we have large populations. It starts with the smallest type of thing and winds up with the human being being

able to survive from that production. It is just a question of how much you get.

Dr. WOLFE. Yes, sir; and the subsequent effects of erosion. I would like you to carry that arctic picture into our own area. The subseqeunt effects of erosion render the lakes and the ponds and the streams turbulent, unable to produce, and the food chain is then impaired, although we do have other resources. The Eskimo has only the algae.

I use that as an example to simplify the chain as it would occur in the Temperate Zone.

Representative DURHAM. It depends on just how big a dose you would get.

Representative HOLIFIELD. Doctor, when we looked at the attack concentration in the northeastern part of the United States, would not this produce a problem in the Maine and Canadian forests?

Dr. WOLFE. I mentioned somewhere that from Maine to Virginia the coniferous and the dry deciduous forests would be wiped out.

Representative HOLIFIELD. This is pertinent, I think. We have had some very bad forest fires in the Los Angeles watershed. A group of the southern California Congressmen were taken over this area last year in helicopters. We got out in some of the burned over areas and looked around. We were shown the replantings of pine trees by the Forest Service. They showed us a 30-foot tree, and they said, "This takes 30 years, to get a tree, a pine tree, up to 30 feet high."

So the picture you paint here of fire destruction would be a destruction that would last over many decades, before we could even begin to get back to the point where we are today in our forests. Of course you would be faced, during all of that period, with tremendous erosion problems, due to the lack of soil-holding roots.

Will you proceed with your statement?

Dr. WOLFE. In Eastern United States, the dry oak and pine forests of the Blue Ridge and Appalachians from New England to Virginia, adjacent to multiple detonations, would undergo a like fate, as well as the pine on the southern Atlantic and Gulf Coastal Plains. In the agricultural land of the Mississippi Valley, with the crops harvested, fire is likely to be more local, less severe, but widespread. Add to this denuding effects of radiation and/or chemically toxic materials.

With the coming of spring thaws especially in the mountains, meltwater from the mountain glaciers and snowfields would erode the denuded slopes, flood the valleys, in time rendering them uninhabitable and unexploitable for decades or longer.

Now, I do not mean to paint a spectacular picture here, but once the forces of erosion get into operation on three dimensional terrain, it is difficult if not imposisble to check until there is some balance regained. There will be an invasion of plants, and a succession of plants back to the original kind of forest is to be expected. But in forests that are dominated by species of 400 and 500 years old, it would take perhaps 1,000 years to get them back in that condition.

Removal of the turf by fire and erosion on plains and prairie would result in uncheckable erosion by wind.

I think it would be impossible to estimate the area that would become dust bowl, but with the removal of the turf, the wind, which is omnipresent in the plains area, would form blowouts, and these would continue expansion. And we have found no way to stop wind

erosion. I am sure that it would not have been as great had it not been plowed or overgrazed. I am not saying that we caused the dust bowls by the activities of man. There were dust bowls before man got there. But we certainly expanded them. And this would in great degree expand them further.

Representative DURHAM. What effect, Doctor, do you think it would have on our coal supply? I am thinking of the difficulty of controlling fires in the peat moss area, which has burned for years and years, as you know. I was thinking of our coal supply. Did you take that into consideration? What would happen?

Dr. WOLFE. I know of these mine fires. But I was afraid to suggest that enough coal mines would get ignited to make an issue of it here.

Representative DURHAM. Well, it is one of the factors, of course, in the survival of man. Without energy we were not making much progress, you know. And it is still one of the main things. We are trying to supplement it with atomic energy, but we find it difficult.

Dr. WOLFE. It means that there will have to be the development of other energy. It is not a question of development of energy; it is what we are going to do if we do not.

Representative DURHAM. Well, if it gets hot enough, you know it is going to burn. It will burn underground as well as above ground.

Dr. WOLFE. I would agree that the coal seams could be ignited as a result of this.

I also take into consideration the fact that where these bombs are marked on the map are not precisely where they are going to land. I do not know how far they would miss.

Representative HOSMER. As a matter of fact, Doctor, the fires that you are talking about mostly, I think, would arise from the misses rather than the hits, would they not? Because these hypotheticals are aimed largely at the metropolitan areas.

Dr. WOLFE. I would hesitate to agree with you on that. I think if you get a perfect hit on Los Angeles, you are going to burn the rest of the watershed.

Representative HOSMER. Well, I think that is probably true.

Dr. WOLFE. You would not expect perfect hits.

Representative HOLIFIELD. Of course, Pittsburgh, I believe, is built right over the coal fields, is it not? And there may be other cities that have coal seams under them. I think there are.

Dr. WOLFE. I think that would be a rather uncomfortable area for some time after the detonation.

Representative HOLIFIELD. Yes; I think so.

Dr. WOLFE. Emergency overgrazing, and cultivation (if there were those to work) would wreak further havoc.

This seems a simple concept, but the effects are indescribable in their immediate implications, almost incalculable in their lingering results before ecological processes attain ascendancy and begin the long march back to equilibrium. It would be almost ludicrous to assess present losses of natural living resources resulting from cigarette butts and camp fires against those that would be generated by surface-detonated nuclear devices, the latter augmented by absence of any effort of control.

Along with fire, flood, and erosion, which would also decrease productivity of the landscape or render it inaccessible to people in uncon-

taminated refugia, would come intensification of disease, plant and animal, including man. Moreover, in the less irradiated areas, which would serve as refugia for animals and man, populations of deleterious animals, especially insects, would move in—a further detriment to food production and contributing further to its unavailability to surviving people.

Man's access to succor through hospitalization, treatment, communications, et cetera, would be meager, and thus the inroads of starvation would be accentuated by increased incidence and intensity of disease.

I do not mean that starvation is likely to eventuate, but the beginnings of starvation would be intensified by these factors.

The immediate physical effects (other than radiation) could be particularly catastrophic in such areas as the Los Angeles watershed, where the city is almost surrounded by vegetation susceptible to the inroads of fire. Those islands relatively free of radioactivity in the early stages would be increasingly contaminated as well by redistribution of radioactive materials by wind, water, biotic migration, and precipitation. Radiation effects are more adequately described elsewhere, but it seems necessary to point out that in a dynamic environment, no area can be regarded as completely isolated from contamination. Indeed, animals that are able to move into the "clean" areas will be contaminated survivors from adjacent areas, and probably (both wild and domesticated) will be unfit for human food.

Representative HOSMER. What do you mean by that, Dr. Wolfe? Do you mean that these animals that have irradiation doses will induce them into animals that do not?

Dr. WOLFE. No, but if they are radioactive and are a source of food, they will move into an area where they are a source of food, and this contaminates that area for whatever eats them.

Representative HOSMER. You mean for animals, or what?

Dr. WOLFE. An animal from the grass line that has eaten radioactive grass and then becomes a source of food for a man somewhere else—is this not moving radiation by the food chain?

Representative HOSMER. It is, but I read yours in the context that the animals contaminated will be moving into clean areas, and they will in turn contaminate survivors from these adjacent areas.

Dr. WOLFE. Well, in my picture, which may be inadequate, I do not think of the entire country being equally contaminated. I think it will all be contaminated, but some areas will be areas in which no life can continue to exist for at least a while. Other areas will be less contaminated. And it is these areas in which there will be a tendency for survival, increase in population by reproduction, and by migration.

Representative HOSMER. How are they going to contaminate survivors if unfit for human food?

Dr. WOLFE. I do not understand your question.

Representative HOSMER. It is the sentence at the beginning of your statement.

Representative DURHAM. It is not like control of leprosy. We can always put them in a pen, and you can control that. But where you have a wide distribution of animals, just taking the rabbit as one thing, of course, and you have deer and everything else in that section

of the country. In North Carolina we have seen deer that have come from the western part of the country. A goose from Canada has been taken. These animals are tagged, and they are killed in all parts of the country today.

Representative HOSMER. I can understand that in particular cases, but I cannot understand it en masse.

Dr. WOLFE. I leave the wrong impression with you. Migration of animals, except in the cases of birds and fish and certain marine mammals, does not occur en masse. It is a gradual process.

Representative HOSMER. I think undoubtedly our food monitoring would be a part of any survival process. But I do not think that this mobility of the animals is going to complicate that beyond a reasonable extent.

Dr. WOLFE. Well, it is a biological contribution to the dispersal of radioactivity.

Representative HOSMER. Are you talking about the next generation and the generations and generations beyond that, of animals?

Dr. WOLFE. No; I am talking about October the 18th, 19th, 20th, and November the 1st. I am building a picture here that leads me to believe that the survival of man or the rebuilding of his culture and his way of life will be impaired by environmental considerations and biological considerations which have been the result of nuclear attack.

Representative HOSMER. I think that is quite true. I just did not want to gather from your statement a greater magnitude order than is true. I think it is going to be bad enough, anyway. We do not want to make it worse.

Dr. WOLFE. This will decrease with time, this migration into uncontaminated areas. I think the uncontaminated areas will also be polluted by wind and water as well. But the point I am trying to make is that this is a dynamic environment, and an uncontaminated area will not remain so.

Representative HOSMER. I think the witnesses all the way through have directed their testimony to that particular point, have they not?

Dr. WOLFE. Well, I have not heard all the testimony.

Representative DURHAM. I think your assumption is correct, Doctor. It is not just a question of the local areas. He has to survive from plant life. He always has. And contamination can be transferred in many many forms. I think you face a very serious thing there, and I think your point is well taken.

Representative HOLIFIELD. There might be some transference of radioactivity from a contaminated animal to another animal. I think probably the record here should show that strontium 90, as a rule, seeks the bone of an animal, and isotopes such as cesium 137 might be deposited in the muscles and the edible part of the animal. On the other hand, the amount that might be residual in the meat part of the animal, if the animal were living, would not be a strong factor. The process of the elimination or discrimination would take place there, and, therefore, the transference to the animal who ate the slightly contaminated animal. And we would have to consider that the animal was not really heavily contaminated, or he would have been dead. There might be a factor there, but I would not think the picture would be overdrawn on that particular point.

That would be my judgment on it, and I am certainly not equipped professionally to substantiate that, except from the volumes of testimony.

Dr. WOLFE. I thought I would have less trouble with that statement than any of the ones I have made. You can strike that one out. The principle is more important.

Representative HOSMER. It might be our confusion on the point where somebody had been exposed to radiation, that it is like a disease, to be passed on. That is simply not true. You do not have to be worried about someone catching radiation from one who has been exposed.

Dr. WOLFE. I did not mean to imply that.

Representative HOLIFIELD. Proceed, Doctor.

Dr. WOLFE. I visualize those people unsheltered in heavy fallout areas after 3 months, to be dead, dying, sick, or helpless; those sheltered, if they can psychologically withstand confinement for that period, to emerge to a strange landscape. The sun will shine through a dust-laden atmosphere, the landscape in mid-January would be snow-covered or blackened by fire in a mosaic. I do not mean it will be snow or black. There would be a mosaic of burned areas.

At higher latitudes blizzards and subzero temperatures would add death and discomfort; both food and shelter would be inadequate and production incapacitated.

In Dr. Reitemeier's remarks, he seemed to think that the harvest would mostly be over and the foodstuffs put away. As I gather, this attack is not going to be announced, if it becomes reality, and a lot of food would not be put away, and would be lost by fire.

Representative HOLIFIELD. I think he was depending on the time of the year. October 18th is a date by which much of the hay and wheat and barley and oats have been harvested. That was his reference to that. Any left out in the open would be subject to fire and contamination, certainly, even though it had been harvested, if it were in stacks.

Dr. WOLFE. It was a minor point.

Representative HOLIFIELD. But I think your reference there to "the sun will shine through a dust-laden atmosphere" is very correct. And I am going to ask Colonel Lunger to state what happened in the Mike shot.

You were there, Colonel Lunger, and participated in that test.

Colonel LUNGER. I think the chairman is referring to the time when we detonated the first thermonuclear device. I can remember very clearly we fired from afloat, it was the first time in the history of test operations that we had to go afloat. We shot early in the morning and the entire task force was steaming north and south trying to keep out from under the local fallout. Late in the evening of shot day I remember we were in the ward room getting our first hot meal, and they came down and told us there was a phenomenon on deck we should see. It was just about sundown. We got on deck, and there was an amber glow along the entire horizon. It was the most artificial thing I have ever seen and sensed in my life. We had displaced many millions of tons of coral debris that had been lifted up to forty and fifty thousand feet by the blast. The crater formed by the detonation was approximately 185 feet deep by a mile and a

quarter across. You can visualize the displacement. This phenomenon was caused by the diffusion of light through the particles in the atmosphere. Keep in mind too it was a detonation of only about 10 megatons.

So the picture that Dr. Wolfe has presented here is very real. When you multiply this phenomenon I have described by approximately 200 weapons in this hypothetical attack, it would be a psychologically unreal world for quite a period after the attack.

Dr. WOLFE. I thought somebody would disagree with that.

Representative HOLIFIELD. Well, you see, you were nearer right than you thought.

Dr. WOLFE. I told you at the start that this was difficult of assessment.

Come then spring floods, and soon after, adding measurably to the disrupted pattern of human existence, are the weather events such as hurricane and tornado, for which there is no defense, and after which there will be little aid.

Perhaps we have dwelled too long on the immediate effects, but it is these that trigger the longtime processes that result in environmental changes of long duration—and therefore changes in the biotic composition of communities that can live under these changed conditions.

But as I suggested at the outset, long-term ecological effects of nuclear war are difficult to assess, however, with the advent of that first spring, I would assume the beginnings of a gradual return to equilibrium of the biological environment. I would anticipate that in springs and summers in the decades that follow biotic succession would continue, leading to full ecological recovery.

The role of North American man in this long-term view of environment—his nationality, genetic constitution, psychological makeup, and creative potential, 3, 10, or 100 generations later, I leave for others to predict.

Representative HOLIFIELD. Thank you very much.

This was our last witness for today. The morning session tomorrow will be opened with a presentation of detailed casualty estimates by target area. Testimony will be given by Mr. Eugene Quindlen of the Office of Civil and Defense Mobilization.

Dr. Willard Libby, Commissioner of the Atomic Energy Commission, will discuss emergency protection measures.

Mr. Herman Kahn of the Institute of International Studies of Princeton University will make a presentation on the major implications of these hearings.

And following this, a panel, the members of which will be announced later, will discuss these implications. That will close the hearings.

The meeting is adjourned.

(Dr. Wolfe's prepared statement follows:)

LONGTIME ECOLOGICAL EFFECTS OF NUCLEAR WAR

John N. Wolfe, Chief, Environmental Science Branch, Division of Biology and Medicine, U.S. Atomic Energy Commission

ABSTRACT

The longtime ecological effects of nuclear war are nearly impossible to assess and even difficult to speculate about. One can only think in terms of major

ecological factors that would be intensified or triggered, and follow the chain of cause and effect to some plausible ultimate set of environmental conditions. Rather than a catalog of effects, only a general picture can be painted, and that in broad strokes.

The obliteration of life in all its forms in continental areas is almost inconceivable and the ultimate recovery of the landscape would be certain in some pattern, probably not unlike the primeval distributions of forest, woodland, desert, and grassland on this continent.

Let us begin with the impressive facts that life in North America and in the adjacent seas has undergone a considerable array of environmental changes since biotic beginnings. Submergence and emergence of the land masses, erosion to base level, mountainbuilding, multiple climatic fluctuations, glaciation, not to mention invasion by the Europeans are major examples. All of these processes are still in operation.

Nuclear war, as it is possible for me to visualize it within my limitations, would scarcely match the effects of these processes on life in the total picture—although landscape recovery in some areas might be in terms of decades or centuries.

Even radiation effects on genetic systems might be considered in the long run to result in only the elimination of the unfit—i.e., the organisms (biotypes) unfit for the environment brought about by this kind of environmental modifications.

However, omitting consideration of radiation for the present, widespread damage due to the thermal and blast components of the bomb would occur in many kinds of biotic systems.

Fire, for example in the dry season of mid-October, would spread over enormous areas of dry western coniferous forests and in the grasslands, with concomitant destruction of natural living resources and their habitats. It is most likely, in my opinion, that these fires would go unchecked until quenched by the winter snows, spreading over hundreds of thousands of square miles. In eastern United States, the dry oak and pine forests of the Blue Ridge and Appalachians from New England to Virginia, adjacent to multiple detonations, would undergo a like fate, as well as the pine on the southern Atlantic and Gulf Coastal Plains. In the agricultural land of the Mississippi Valley, with the crops harvested, fire is likely to be more local, less severe, but widespread. Add to this denuding effects of radiation and/or chemically toxic materials.

With the coming of spring thaws, especially in the mountains, melt water from the mountain glaciers and snowfields would erode the denuded slopes, flood the valleys, in time rendering them uninhabitable and unexploitable for decades or longer. Removal of the turf by fire and erosion on plains and prairie would result in uncheckable erosion by wind, with subsequent expansion of present "dust bowls" and creation of new ones of wide extent. Emergency overgrazing, and cultivation (if there were those to work) would wreak further havoc.

This seems a simple concept but the effects are indescribable in their immediate implications, almost incalculable in their lingering results before ecological processes attain ascendancy and begin the long march back to equilibrium. It would be almost ludicrous to assess present losses of natural living resources resulting from cigarette butts and camp fires against those that would be generated by surface-detonated nuclear devices, the latter augmented by absence of any effort of control.

Along with fire, flood, and erosion, which would also decrease productivity of the landscape or render it inaccessible to people in uncontaminated refugia, would come intensification of disease, plant and animal, including man. Moreover, in the less irradiated areas, populations of deleterious animals, especially insects, would move in—a further detriment to food production and contributing further to its unavailability to surviving people.

Man's access to succor through hospitalization, treatment, communications, etc., would be meager, and thus the inroads of starvation would be accentuated by increased incidence and intensity of disease.

The immediate physical effects (other than radiation) could be particularly catastrophic in such areas as the Los Angeles watershed, where the city is almost surrounded by vegetation susceptible to the inroads of fire. Those islands relatively free of radioactivity in the early stages would be increasingly contaminated as well by redistribution of radioactive materials by wind, water, biotic migration, and precipitation. Radiation effects are more adequately described elsewhere,

but it seems necessary to point out that in a dynamic environment, no area can be regarded as completely isolated from contamination. Indeed animals that are able to move into the "clean" areas will be contaminated survivors from adjacent areas, and probably (both wild and domesticated) will be unfit for human food.

I visualize those people unsheltered in heavy fallout areas after three months, to be dead, dying, sick, or helpless those sheltered, if they can psychologically withstand confinement for that period to emerge to a strange landscape. The sun will shine through a dust-laden atmosphere, the landscape in mid-January would be snow-covered or blackened by fire; at higher latitudes blizzards and subzero temperatures would add death and discomfort; both food and shelter would be inadequate and production incapacitated. Come then spring floods, and soon after, adding measurably to the disrupted pattern of human existence, are the weather events such as hurricane and tornado, for which there is no defense, and after which there will be little aid.

Perhaps we have dwelled too long on the immediate effects, but it is these that trigger the long-time processes that result in environmental changes of long duration and therefore changes in the biotic composition of communities that can live under these changed conditions.

But as I suggested at the outset, long-term ecological effects of nuclear war are difficult to assess, however, with the advent of that first spring, I would assume the beginnings of a gradual return to equilibrium of the biological environment. I would anticipate that in springs and summers in the decades that follow biotic succession would continue, leading to full ecological recovery.

The role of North American man in this long-term view of environment—his nationality, genetic constitution, psychological makeup, and creative potential, 3, 10, or 100 generations later, I leave for others to predict.

(Whereupon, at 4:40 p.m., Thursday, June 25, 1959, the hearing was adjourned, to reconvene Friday, June 26, 1959, at 10 a.m.)

BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

FRIDAY, JUNE 26, 1959

CONGRESS OF THE UNITED STATES,
SPECIAL SUBCOMMITTEE ON RADIATION,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D.C.

The subcommittee met at 10:20 a.m., pursuant to recess, in room P-63, the Capitol, Hon. Chet Holifield presiding.

Present: Senator Anderson (chairman), Representatives Durham, Holifield, Price, and Hosmer.

Also present: Richard T. Lunger, staff consultant, and Carey Brewer, special consultant, Joint Committee on Atomic Energy.

Representative HOLIFIELD. The committee will be in order.

We plan to conclude our 5 days of hearings today. It may be necessary to shift the witnesses. Dr. Libby had planned to be here at 11, but he is fogged in by weather in New York. He may be late, so we might put him on in the afternoon if we get word that he has left New York in time to get here for the afternoon session.

Our first witness this morning is Mr. Eugene Quindlen from the Office of Civil and Defense Mobilization. He will give us a presentation on casualty estimates in detail by different cities and regions.

Mr. Quindlen, you may proceed.

STATEMENT OF EUGENE QUINDLEN,[1] OFFICE OF CIVIL AND DEFENSE MOBILIZATION

Mr. QUINDLEN. Thank you, Mr. Chairman.

This presentation includes, as requested by the committee, a further analysis of the effects of the attack specified by the committee upon the people of the United States.

We have broken down the assessment of effects on people by metropolitan area as well as by State and by OCDM region.

We have noted in our review of the individual metropolitan area figures a considerable variation in the effects from one city to another. This results from the factor of the application of the random bombing error which applies as scientifically as possible the factors of chance which are present in any attempt to place a weapon upon a target.

Representative HOLIFIELD. At that point, Mr. Quindlen, I would like for you to explain what the random bombing error formula is, so that we might know.

[1] See biography, p. 12.

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Mr. QUINDLEN. Yes, sir. In selecting the points at which these weapons actually are detonated, we applied a random bombing error of 1 miles, 5,280 feet. This might be slightly high for an aircraft-delivered weapon, but this would be subject to some argument. It would be low, that is, conservative, for missiles, since missile error might be considerably larger.

We have used a probable error rather than a standard error; probable error being the measure of the distance from a target within which the weapon would fall half of the time. For example, if the target were a certain airbase, with a probable error of 1 mile, we could expect half of the weapons to fall within the distance of 1 mile from the target. We could expect the other half to fall outside of 1 mile and up to, in rare instances, perhaps, 4 miles. It is a distribution by a normal curve, as the statisticians say, and it is figured on the basis of the chance distribution of the errors.

Now, we have not, in any instance, calculated complete miscarriage. That is, we have not had a weapon which was destined by the enemy for St. Louis which detonated in North Dakota. We have not done that, because this was not within the charge which we received.

Representative HOLIFIELD. Would this miscarriage situation you mentioned be the result of an erratic missile?

Mr. QUINDLEN. Or a plane which was shot down by our active defenses.

Representative HOLIFIELD. Shot down on the way in?

Mr. QUINDLEN. Yes, sir, long before it reached the target. We have not figured that and have calculated only a random error with respect to the target itself.

Representative HOLIFIELD. I see. I noticed, in going through the list hurriedly, that there is a very light casualty rate, comparatively speaking, in Chicago.

Mr. QUINDLEN. I would like to get into that.

Representative HOLIFIELD. I know you do go into it. I also notice that there was no one killed in Vermont.

Mr. QUINDLEN. No one killed the first day in Vermont.

Representative HOLIFIELD. Yes, sir. You do expect to go into detail, however, on those things?

Mr. QUINDLEN. Yes, sir, I do.

Representative HOLIFIELD. Did you use the factor of missile delivery as well as plane delivery in computing these circles of probable error?

Mr. QUINDLEN. Sir, we used a standard 1 mile, and we made no distinction. That is, we made no choice between the 263 weapons, as to which were missile and which were aircraft-delivered or delivered by any other means.

Representative HOLIFIELD. What is the source of that formula?

Mr. QUINDLEN. I think primarily, Mr. Chairman, from the military information as to ordinary delivery upon targets. Some people use 4,000 feet, instead of 5,280. We felt that we were still being conservative when we applied it, since this was supposed to be both an aircraft and a missile attack, and with missiles there could be far greater errors than this.

Representative HOLIFIELD. Of course, that error, that distance error, in the type of weapons used here, would still bring it within the area of the circle of grave damage in all instances.

Mr. QUINDLEN. Yes, sir. Now, if we were discussing a long-range missile, an intercontinental missile, perhaps traveling 5,000 miles, if you had just a one-tenth of 1 percent error you would still have a probable error of as much as perhaps 4 or 5 miles.

Representative HOLIFIELD. This is the problem that we will face later on, face in some great fashion, if the scientists' predictions as to the development of accuracy in intercontinental ballistic missiles are borne out. As to the predictions of the time element, this will get tighter and tighter as far as the miss-distance is concerned.

Representative DURHAM. Is that regardless of the size of the weapon?

Mr. QUINDLEN. Yes, sir. It is related to the means of delivery rather than to the size of the weapon.

Representative HOLIFIELD. All right. Proceed.

Mr. QUINDLEN. The 71 metropolitan areas which are the population and industrial centers hit in this attack are listed on table 1 which is now before the committee. I would like to direct your attention to the first two groups which are the 12 largest of these areas. You have this material also on your table 1. We wanted to draw out these first two groups.

These represent groups that receive the heaviest in the way of the attack, two 10-megaton weapons each on the first six, and one 10- and one 8-megaton weapons on the second six. These 12 areas contain about 28 percent of the population of the United States.

The first table summarizes the specific effects for these 12 areas. The cities listed here and their surrounding areas received heavy damage. Of the total of 19.7 million killed the first day, about 11.4 million came from these areas. Similarly, of the 22.2 million fatally injured, about 10.9 million were from these 12 metropolitan areas.

TABLE 1.—*Effects on individual metropolitan areas*

[In thousands]

Target area and weapons	Number of people in attacked areas [1]	Number killed 1st day	Number fatally injured	Number surviving injured
2 10-megaton weapons each:				
Boston	2,875	1,052	1,084	467
Chicago	5,498	545	447	648
Detroit	3,017	820	593	557
Los Angeles	4,367	698	2,136	814
New York City	12,904	3,464	2,634	2,278
Philadelphia	3,671	1,309	989	777
Subtotal	32,332	7,888	7,883	5,541
1 10- 1 8-megaton weapon each:				
Baltimore	1,338	591	466	174
Cleveland	1,466	394	298	316
Pittsburgh	2,214	597	659	43
St. Louis	1,292	563	370	161
San Francisco	2,241	734	769	301
Washington, D. C	1,465	579	433	228
Subtotal	10,016	3,458	2,995	1,223
1 10-megaton weapon each:				
Atlanta	672	155	206	160
Buffalo	1,089	253	140	158
Cincinnati	904	461	261	93
Dallas	614	130	314	124
Houston	807	81	57	114
Kansas City	814	265	230	144
Milwaukee	872	151	112	189
Minneapolis	1,117	201	92	97
New Orleans	685	319	226	74
Portland	705	156	103	131
Providence	682	210	263	144
Seattle	732	168	99	126
Subtotal	9,693	2,550	2,103	1,554
1 8-megaton weapon each:				
Albany	514	69	51	63
Birmingham	559	159	137	86
Columbus	504	245	134	54
Dayton	458	200	119	58
Denver	564	138	144	118
Indianapolis	552	137	88	109
Louisville	577	264	156	50
Memphis	482	76	51	97
Norfolk	446	180	117	50
Rochester	488	212	107	50
San Diego	557	58	202	126
Youngstown	529	121	189	76
Subtotal	6,230	1,859	1,495	964
1 3-, 1 2-megaton weapon each:				
Akron	410	162	104	66
Allentown	436	45	79	117
Fort Worth	361	73	189	74
Hartford (New Britain)	539	124	110	119
Springfield-Holyoke	456	157	100	72
Toledo	396	107	74	75
Wilkes-Barre	393	51	48	63
Subtotal	2,991	719	704	586

See footnote at end of table.

TABLE 1.—*Effects on individual metropolitan areas*—Continued

[In thousands]

Target area and weapons	Number of people in attacked areas [1]	Number killed 1st day	Number fatally injured	Number surviving injured
1 3-, 1 1-megaton weapon each:				
Bridgeport	504	105	84	54
Canton	283	84	59	42
Chattanooga	246	85	77	29
Davenport	234	73	53	53
Erie	219	54	42	42
Flint	271	77	46	39
Grand Rapids	287	124	66	21
Knoxville	337	112	106	38
Lancaster	235	54	51	49
New Haven (Waterbury)	546	192	188	95
Peoria	250	84	54	28
Reading	256	72	66	60
South Bend	205	84	53	34
Syracuse	342	89	68	73
Trenton	230	41	80	97
Utica-Rome	284	107	60	2
Wheeling	355	59	58	46
Wichita	222	78	75	38
Wilmington	269	77	76	67
Worcester	547	128	151	97
Subtotal	6,122	1,779	1,463	1,004
1 1-megaton weapon each:				
Binghamton	185	58	32	17
Evansville	161	60	34	23
Fort Wayne	184	69	41	23
Greensboro	191	28	19	32
New Britain (included with Hartford).				
Rockford	152	42	25	25
Waterbury (included with New Haven).				
York	203	46	31	17
Subtotal	1,076	303	182	137
City target area total	68,460	18,556	16,825	11,009
Nontarget area total	82,239	1,095	5,354	6,182
Grand total	150,699	19,651	22,179	17,191

[1] 1950 population figures.

Representative HOLIFIELD. In the case of those fatally injured, did you compute the time between injury and death?

Mr. QUINDLEN. These would be those dying within 60 days, sir.

The number killed the first day was by far the heaviest in New York City with 3,364,000 killed in the first 24-hour period and an additional 2,634,000 fatally injured. Chicago, on the other hand, had 545,000 killed and 447,000 fatally injured.

There is a very important point here which I want to emphasize and I will use this second table to do it. This attack resulted in considerable variation from city to city. In Boston, for example, 75 percent of the persons living in the area were killed, while in Chicago the figure was only 18 percent. In Chicago about 70 percent of the people were not injured at all and an additional 12 percent were injured but will survive. Let us look at Los Angeles. Sixty-five percent of the people in the area would eventually die from this attack, but most of these would not die immediately. This is a substantially different picture from that for some of the other large cities.

TABLE 2.—*Comparison of attack effects on 12 largest metropolitan areas*

Target area and weapons	Percent killed first day	Percent fatally injured	Percent surviving injured	Percent uninjured
2 10-megaton weapons each:				
Boston	37	38	16	9
Chicago	10	8	12	70
Detroit	27	20	18	35
Los Angeles	16	49	19	16
New York City	27	20	18	35
Philadelphia	35	27	21	17
1 10- 1 8-megaton weapons each:				
Baltimore	44	35	13	8
Cleveland	27	20	22	21
Pittsburgh	27	30	2	41
St. Louis	44	29	12	15
San Francisco	33	34	13	20
Washington, D.C	39	30	16	15
Total	27	26	16	31

Mr. QUINDLEN. Going down to the second group of cities, we notice that Cleveland did not sustain, for example, nearly as devastating an attack as did Baltimore. The point we should emphasize here is that this is the result for this particular attack with these weapons on this day, which happens to be a typical mid-October day. A variation even in wind patterns could affect these casualty figures. A different attack pattern, the failure of enemy aircraft, interceptions by our active defenses and many other factors could result in an individual city being spared or being less heavily damaged than this material indicates.

Representative DURHAM. What are some of the reasons for that differential? Could you be specific?

Mr. QUINDLEN. The reason primarily is that in any delivery of this sort, in any attack by air or by missile, there are many chance factors—the question of whether particular aircraft keep running during the attack, whether there is engine failure, the effect of our active defenses, and this matter of random bombing error.

Representative DURHAM. Did you try to calculate it on the basis of our active defense against these missiles?

Mr. QUINDLEN. No, sir. We did not. But we do want to make the point that if we took this attack pattern and had a different wind pattern along, or we applied a second time the random bombing error, a weapon which landed on the north side of a city might land on the south side of a city, and this could result in a different number of deaths and a different number of injuries.

Representative PRICE. I think you told the chairman you are going to be specific, now, on why the situation at Chicago is as you computed in your table, here. In other words, you have been general about what could affect the situation. But in your computation, what did you do as to the basis for the difference?

Mr. QUINDLEN. I will give you the specific information, Mr. Price, as to where the Chicago weapon landed as compared to where the New York weapons landed.

Representative HOLIFIELD. I can understand your reasoning, that there would be different effects if there were different wind paths. But I would like for Colonel Lunger to question you on some of the things you have said. It seems to me some things need clarification.

Representative PRICE. Then you will straighten out the Chicago situation?

Mr. QUINDLEN. Yes, sir.

Colonel LUNGER. I think the record should very specifically point out that the problem as given to your agency—and this has been pointed out in our original attack pattern; furthermore it was pointed out in all our briefings to the agencies involved—that one must start in a hypothetical situation like this from a very common basis, so that all the subsequent analyses by the various experts and agencies that we have brought in are essentially stepping off from a common base. That is the only reason that this initial situation or attack pattern was prescribed by the committee. This is the prime reason that the committee elected to set up this attack problem itself, without the help of any agency of the Department of Defense. We did not want to "war-game" this in any way. We put this problem on the ground. We placed the 260 or so weapons on the ground. We took all the factors into consideration prior to setting up the so-called scenario for the attack.

Now, kill rates, weather, aborts of aircraft, aborts of missiles, and aborts of submarine delivered missiles were cranked in prior to the laying down of this pattern that we furnished your folks to step forward from. I want to make that perfectly clear in the record. The figures that are given here originate from the fact that we had a detonation of 263 weapons. The total of 263 weapons included a spectrum of yields as follows: 10 megatons, 8 megatons, 3 megatons, 2 megatons, and 1 megaton. All of the detonations in the attack pattern were prescribed as ground bursts.

Mr. QUINDLEN. Yes, sir. I have no argument, no difference of opinion, with that.

Representative HOLIFIELD. The remark, then, as to whether an airplane was not downed has nothing to do with this pattern, actually.

Mr. QUINDLEN. But it would have much to do with any subsequent pattern that the committee should select or we would select in our planning. It is a factor which has to be considered each time an attack pattern is placed for purposes of assessment.

Representative HOLIFIELD. That is true. But this was considered, as Colonel Lunger says, before laying down the pattern for computation purposes.

Mr. QUINDLEN. Yes, sir. That is true.

Now, we were given for purposes of our assessment the targets that were hit. It certainly would not be realistic for us to take each of these weapons and place them at 42d and Broadway or at 14th and G, and so we did apply this factor, which has resulted in these different results.

This point of variation is extremely important, because the people of New York City might look at this pattern and say, "An attack on this country would present an impossible situation for the people of New York City."

On a subsequent attack, with different factors, under different circumstances, an individual city might be spared. Or the situation of Chicago and New York might be directly reversed. And I want to make this point very strongly, because the major cities have to prepare for two roles—the situation where they are attacked, and the

situation where they are perhaps spared, have to be ready for fallout defense, and to render support in the general rehabilitation and restoration of the country.

Colonel LUNGER. I could not agree more with your analysis, here, Mr. Quindlen, and therefore if we are, as they say, baring our souls in the tools of this trade, I think we should further project this and leave no question in the mind of the public whatever that when you look at these beautiful asymmetrical fallout patterns that we have displayed before us, let us face life: The only real fallout pattern that we are going to get and going to chart is with adequate dosimetry instrumentation on the ground and after the fact.

Mr. QUINDLEN. Sir, all of our publications on fallout prediction and measurement emphasize this fact. And I think the clearest statements on this point are to be found in the OCDM publications.

Representative HOLIFIELD. I am not quarreling with this random method of obtaining the location of ground zero. I think you are completely right in using that. But I did not want these other factors to be brought in as factors which enter into the computation of damage.

Mr. QUINDLEN. No, sir. We are casting no question on this pattern. As it was presented to us, it was presented as a net attack. And I was explaining that therefore we had not figured aborts, as they say, of weapons in our calculations.

Representative PRICE. Why would the situation be so much different in Chicago than in the other areas?

Mr. QUINDLEN. In Chicago, according to the figures which I have here—and I do not have the specific coordinates with map reference—the two weapons landed in Evanston and Chicago Heights. Now, I have not examined the Chicago situation specifically to see, but of course Chicago has a large area, as does Los Angeles. And this is where the weapons landed, rather than at State and some important intersection in downtown Chicago.

Representative HOLIFIELD. In other words, following your random formula of specific hits, some of the cities, by mathematical formula, came up as being not hit in the center, some south of the center, some north, some upwind, some downwind, and other factors?

Mr. QUINDLEN. Yes. In some others there were much closer hits. The two hits in Washington——

Representative HOSMER. Before you go to that, can you give us an idea, within the limits of the problem that you had, the variables, of by what order of magnitude those specific numbers could vary?

Mr. QUINDLEN. I think, Mr. Hosmer, if we look at table 2 again, (p. 848) on which we used percentage figures for these same 12 cities, it might help to illustrate this point.

Representative HOSMER. Will you cover it at that point?

Mr. QUINDLEN. Yes, sir. Then if we had not, we could come back to that question.

This is a comparison to emphasize this point of variation, and I think to address myself, Mr. Hosmer, specifically to your question, you will note that in Boston you have 37 percent killed the first day and 38 percent fatally injured, with 16 percent surviving injured, and only 9 percent uninjured.

The figure for Chicago, given sufficient weapons and good specific placement of weapons, could range up to that degree.

Representative HOSMER. In other words, the actual variation between the maximum and the minimum?

Mr. QUINDLEN. Yes; I think that would be it.

Representative HOSMER. Rule of thumb?

Mr. QUINDLEN. Yes, sir. And this illustrates the tremendous variation which happened in this attack. And in another attack these figures might well, for individual cities, be reversed. And in some cases an individual city in a different attack pattern might have been spared entirely.

Representative HOSMER. In other words, within this problem, the variation is between 10 and 37 percent in the first-day-killed column. You indicated a little while ago that outside this problem it would be zero.

Representative DURHAM. If you had a different attack pattern, of course, your figures would be different in Chicago.

Mr. QUINDLEN. Yes, sir. And a similar difference applies in this type of assessment when you take a specific industry, such as we discussed yesterday. In one attack, it might be hit much harder or much less than in another.

We have provided also a table of effects of the attack by States. These States are grouped by the OCDM regions, that is, the eight areas which the Office of Civil and Defense Mobilization had established for administrative and operational purposes.

Table 2, which members of the committee have before them, shows the breakdown. And we have on this the indications of the number killed by region.

I think table 3 is much more graphic. It also shows the percentage of national casualties occurring in each section of the country.

In most attack patterns which we run, this heavy concentration in our regions 1 and 2 occurs, and I think will occur in most targeting which you would do of this type of attack. Sometimes we get a little heavier on the west coast and in the Northwest than is shown here.

TABLE 3.—*Effects of attack on individual States*

[In thousands]

State and region [1]	Number of people in State [2]	Number killed 1st day	Number fatally injured	Number surviving injured
Region 1 (percentage of national casualties, 29 percent):				
Connecticut	2,007	455	443	380
Maine	914	43	67	77
Massachusetts	4.691	1,347	1,501	878
New Hampshire	533	30	48	41
New Jersey	4,837	291	875	1,209
New York	14,830	4,067	2,702	2,123
Rhode Island	792	210	294	192
Vermont	378	------------	18	24
Total	28,982	6,443	5,948	4,924
Region 2 (percentage of national casualties, 25 percent):				
Delaware	318	78	87	67
District of Columbia	803	440	257	75
Kentucky	2,945	344	246	149
Maryland	2,344	698	648	330
Ohio	7,948	1,657	1,421	1,089
Pennsylvania	10,495	2,164	2,134	1,723
Virginia	3,319	239	231	233
West Virginia	2,006	100	213	158
Total	30,178	5,720	5,237	3,824

See footnotes at end of table.

TABLE 3.—*Effects of attack on individual States*—Continued

[In thousands]

State and region [1]	Number of people in State [2]	Number killed 1st day	Number fatally injured	Number surviving injured
Region 3 (percentage of national casualties, 7 percent):				
Alabama	3,062	169	263	248
Florida	2,771	90	271	245
Georgia	3,444	120	369	417
Mississippi	2,179	31	147	160
North Carolina	4,062	29	300	389
South Carolina	2,117	28	133	134
Tennessee	3,292	272	292	257
Total	20,927	739	1,775	1,850
Region 4 (percentage of national casualties, 14 percent):				
Illinois	8,714	726	686	878
Indiana	3,935	371	371	388
Michigan	6,371	1,020	738	694
Missouri	3,953	801	594	321
Wisconsin	3,435	172	148	258
Total	26,408	3,089	2,537	2,539
Region 5 (percentage of national casualties, 8 percent):				
Arkansas	1,910	4	59	43
Louisiana	2,683	420	443	291
New Mexico	681	92	108	75
Oklahoma	2,234	37	166	172
Texas	7,710	618	1,318	858
Total	15,218	1,171	2,094	1,439
Region 6 (percentage of national casualties, 3 percent):				
Colorado	1,326	167	205	174
Iowa	2,621	88	66	58
Kansas	1,905	113	155	146
Minnesota	2,983	15	17	50
Nebraska	1,325	43	47	84
North Dakota	620	5	5	12
South Dakota	653	1	3	10
Wyoming	291	32	16	....
Total	11,724	464	514	534
Region 7 (percentage of national casualties, 12 percent):				
Arizona	750	58	90	82
California	10,585	1,547	3,598	1,500
Nevada	160	....	23	28
Utah	689	9	16	27
Total	12,184	1,614	3,727	1,637
Region 8 (percentage of national casualties, 2 percent):				
Idaho	588	....	10	20
Montana	591	2	7	16
Oregon	1,521	156	99	114
Washington	2,378	253	231	294
Total	5,078	411	347	444
Grand total	150,699	19,651	22,179	17,191

[1] OCDM regions.
[2] 1950 population figures.

Representative DURHAM. In other words, the pattern of attack would not make such a differential in the casualties on that basis.

Mr. QUINDLEN. Usually the heaviest is in region 1 or region 2. Usually.

Representative DURHAM. You would not be surprised if the pattern of attack would differ?

Mr. QUINDLEN. Yes, depending on the enemy objective. If it were to attack military bases only, or certain types of military bases, it could be substantially different. But a mixed population military targeting often results in this type of situation.

Mr. Chairman, you requested us to reassess the national figures which we presented yesterday based upon the data on radiation curves mentioned by the Naval Radiological Defense Laboratory. Our computer specialists were in touch with members of the NRDL staff, and took their data and applied them to our national figures.

This next table compares the original assessment with the assessment prepared with the NRDL material. You will note that the principal difference relates to the increase of 5.1 million in fatally injured, with an increase also of 1.6 million in surviving injured.

TABLE 4.—*Rerun of attack effects using NRDL data*

[In millions]

	Killed first day	Fatally injured	Surviving injured
Original results	19.7	22.2	17.2
Results with revised curves	19.7	27.3	18.8
Difference	None	5.1	1.6

There is no effect—when I say "no," I mean it is a minimal effect; it is not a significant effect, if any—upon the number killed the first day. This latter point is due to the fact that the deaths on the first day are primarily from blast or thermal effects, with the individuals dying of these effects even though they might also have had substantial exposure to radiation.

We do not wish to conclude our testimony in this matter without reiterating most strongly our conviction that we should always emphasize the survivors rather than the casualties. I personally like the phrase which is used in the rehabilitation of handicapped workers. "It is not what you have lost that is most important, but what you have left."

Representative HOLIFIELD. Mr. Quindlen, this last paragraph, of course, is one way of looking at the matter. But when you are trying to solve a problem, you do not look at the part which is not pertinent to the problem. The problem of survival deals with protecting the people in the first instance. And you are reversing the old adage of the Savior, who found He had 99 sheep in the fold, and 1 had strayed. So He left the 99 and went out to save the 1. In this case, in your last paragraph, here, you are concerning yourself with the 99 that are still in the fold.

Mr. QUINDLEN. No, sir. Our function is to face the effects of an attack and to do, through the State and local governments with the aid of the Federal Government, whatever it is possible to do in the restoration and rehabilitation of the government. And it is the survivors who will do this. That is why we emphasize that point.

Representative HOSMER. As a matter of fact, you are drawing a distinction between individual survival and national survival?

Mr. QUINDLEN. Yes, sir; it is a question of national survival, the common good; as has been emphasized right from the beginning of our history, the common good, which will at no time be as important as it would be after an attack on this country.

Representative HOLIFIELD. You mention the formula of 5 million additional, which, compared to the 40 is roughly one-eighth, in other words, if you used the t to the minus 2 in place of the t to the minus 1.2—Is it t to the minus 2 or 2.7 that you use?

Mr. QUINDLEN. Sir, we are not in a position at this point to put this in a simple formula. Perhaps NRDL can do it. I do not think it is t to the minus 2.

Representative HOLIFIELD. Well, it is an increase of one-eighth. And if you will take your percentages, 1.2 is twelve-tenths.

Mr. QUINDLEN. Yes, sir. It is about one-eighth increase in the fatally injured, sir.

Representative HOLIFIELD. All right. That is one factor. In other words, you would raise these figures by an eighth if you used the later data, the new formula. Now, you are using the 1950 census figures, which are 151 million, as compared to 177 million, which we have now.

To give you an idea, I did a little calculation myself on the Los Angeles area. You used a figure in the Los Angeles area of 4,367,000. I checked this morning with the Los Angeles Chamber of Commerce, and their last census was 5,660,000 plus. Their April 1959 estimate for proportion of gas tax moneys, porportioned on the population basis, is $5,869,000. So the population in this area is one-third larger than you used. This would mean you would have to raise your casualities somewhere in the neighborhood, in relation to population, of a third for the Los Angeles area, and an eighth on the formulas. So you would have a considerably greater figure there.

Mr. QUINDLEN. Sir, you would have a greater figure. But how much greater would depend upon where the increases occurred in Los Angeles.

Representative HOLIFIELD. They occurred everywhere.

Mr. QUINDLEN. Of course, Los Angeles has been a lot more fortunate in population growth than many other cities.

Representative HOLIFIELD. In cities where the population has stayed comparatively still, this would be pretty accurate. In some areas there have been decreases. So there is a compensating factor here, and we want the record to be fair. That is the only reason I bring the matter up.

Mr. QUINDLEN. Yes.

Representative HOSMER. Did I understand you to say, Mr. Quindlen, that you cannot apply straight mathematical formulas to a casualty increase based upon a population increase, because in instances like Los Angeles, where your expansion is out into the suburbs, you get further out away from the effects of the detonation?

Mr. QUINDLEN. Depending upon where the particular weapons hit in the particular city. And this is true. We have felt that you could roughly apply one-sixth on a national basis, but when you go below that you are introducing many inaccuracies.

Representative HOSMER. And what you figures show here is that even under the other formula there are still 130 millions of people left after the attack. That is in itself a not insignificantly powerful national population.

Mr. QUINDLEN. It is a substantial nation, larger than most nations in the world, at that point.

Representative HOLIFIELD. I was just told by members of the staff, and this would be of interest to Chairman Anderson if he were here, that the Albuquerque figures in 1950 were in the neighborhood of 90,000. I understand it is more than 200,000 now. So there is a factor of a two-fold increase. I have not even checked to see if you have Albuquerque on the list.

Mr. QUINDLEN. There are a few cities on our list which I would purposely not mention which have actually decreased in population during that period of time.

Representative HOLIFIELD. Are you finished with your statement?

Mr. QUINDLEN. Yes, sir; I am.

Representative HOLIFIELD. Your entire statement will be included in the record.

(The statement referred to is as follows:)

FURTHER CASUALTY ESTIMATES

(Eugene J. Quindlen)

Mr. Chairman, this presentation includes, as requested by the committee, a further analysis of the effects of the attack specified by the committee upon the people of the United States.

We have broken down the assessment of effects on people by metropolitan area as well as by State and by OCDM region.

We have noted in our review of the individual metropolitan area figures a considerable variation in the effects from one city to another. This results from the factor of the application of the random bombing error which applies as scientifically as possible the factors of chance which are present in any attempt to place a weapon upon a target.

The 71 metropolitan areas which are the population and industrial centers hit in this attack are listed on table 1 which is now before the committee. I would like to direct your attention to the first two groups which are the 12 largest of these areas. These 12 areas contain about 28 percent of the population of the United States.

The first chart (table 1, p. 846) summarizes the specific effects for these 12 areas. The cities listed here and their surrounding areas received heavy damage. Of the total of 19.7 million killed the first day, about 11.4 million came from these areas. Similarly, of the 22.2 million fatally injured, about 10.9 million were from these 12 metropolitan areas.

The number killed the first day was by far the heaviest in New York City with 3,364,000 killed in the first 24-hour period and an additional 2,634,000 fatally injured. Chicago, on the other hand, had 545,000 killed and 447,000 fatally injured.

There is a very important point here which I want to emphasize and I will use this second chart (table 2, p. 848) to do it. This attack resulted in considerable variation from city to city. In Boston, for example, 75 percent of the persons living in the area were killed, while in Chicago the figure was only 18 percent. In Chicago about 70 percent of the people were not injured at all and an additional 12 percent were injured but will survive. Let's look at Los Angeles. Sixty-five percent of the people in the area would eventually die from this attack but most of these would not die immediately. This is a different picture from that for some of the other large cities.

Going down to the second group of cities, we notice that Cleveland did not sustain, for example, nearly as devastating an attack as did Baltimore. The point we should emphasize here is that this is the result for this particular attack with these weapons on this day, which happens to be a typical mid-October day. A variation even in wind patterns could affect these casualty figures. A different attack pattern, the failure of enemy aircraft, interceptions by our active defenses and many other factors could result in an individual city being spared or being less heavily damaged than this material indicates. A different attack pattern or a different placement of weapons might halve this figure for New York or for Boston or might increase the casualties in Chicago. In other words, we cannot predict what would happen in an enemy attack to an individual city. All major

cities must plan for two situations: the one in which they are actually attacked; the other in which they are not attacked and must be ready for fallout defense and subsequent support for other communities.

We have provided a table of the effects of the attack by States. These States are grouped by OCDM regions which are the eight areas OCDM has established for administrative and operational purposes. Table No. 3 (p. 852) shows this breakdown. We also indicate on this map the percentage of national casualties by OCDM region.

You requested us, Mr. Chairman, to reassess the national figures based upon the data on radiation curves mentioned by the Naval Radiological Defense Laboratory. This has been done and I would like now to present the results. This next chart (table 4, p. 853) compares the original assessment with the assessment prepared with the NRDL material. You will note that the principal difference relates to the increase of 5.1 million in fatally injured with an increase also of 1.2 million in surviving injured. There is no effect upon the number killed the first day. This latter point is due to the fact that the deaths on the first day are primarily from blast and thermal effects with the individuals dying of these effects even though they might also have had substantial exposure to radiation.

We do not wish to conclude our testimony in this matter without reiterating most strongly our conviction that we should emphasize the survivors rather than the casualties. I, personally, like the phrase which is used in the rehabilitation of handicapped workers: "It is not what you have lost that's most important, but what you have left."

Representative HOLIFIELD. Are there any questions from any members of the committee?

Representative PRICE. In most of the metropolitan areas throughout the country, why have you not taken the most up-to-date figures available?

Mr. QUINDLEN. Sir, in doing this national assessment by machine, we locate population mathematically at 24,000 points throughout the United States. We worked very closely with the Census Bureau and asked them what sort of a job it would be to bring our population figures for these 24,000 areas up to date. Actually, it approximates the same type of activity as a full national census. This is why we have not done it. If we take an individual city, and we are trying to find out what would happen in an individual city, where we have the up-to-date figures, we use them. But it would introduce error if we took this national figure for national assessment purposes and introduced some up-to-date figures and some not. So we would rather use the best census available to us, which is 1950, and then make it clear that these are the figures which we are using.

Representative HOLIFIELD. For the record, I would like to request that OCDM submit two kinds of information at a later date. And this will be printed in the permanent record.

Mr. QUINDLEN. Yes, sir.

Representative HOLIFIELD. Of course, we would like a statement giving the criteria used to arrive at casualties from the weapons, your working criteria. The second is an estimate of the delayed effects through D plus 90 days. The reason we asked for this later data is that it is needed to evaluate the estimate of genetic effects as well as the numbers of histories of cancer, leukemia, and other delayed effects.

Mr. QUINDLEN. Is that an average figure?

Representative HOLIFIELD. I think that would probably be the only way you could furnish it to us, as an average figure.

I want to again express the thanks of this committee and our staff for the way that OCDM has cooperated with us and the fair way in which you have presented these estimates. I would say that you

have made an honest and earnest attempt to be responsive to the committee's request. Such variables as do exist in these formulas, and in the differences in population—are understandable. This can be taken into consideration by people who wish to pare this down to finer detail.

(The following statement was subsequently submitted by Mr. Quindlen:)

I. Method of Casualty Computation in NDAC Damage Assessment Program

In computing casualties from a hypothetical nuclear attack on the United States, the National Damage Assessment Center computer program assigns each person in the Nation to one of a set of standard locations.[1] These standard locations vary in size from census tracts only a few blocks long in the large cities, through minor civil divisions in the suburbs, to whole counties in sparsely settled areas. To make the computation manageable, even with a high-speed computer, it is necessary to suppose that the entire population of each standard location is concentrated at a central point. Since the standard locations are small in the densely populated areas, this generalization is not regarded as a source of significant error.

Computation of the casualty percentage from direct effects (blast thermal, and direct radiation) is based on the distance from the center of the standard location to the nearest ground zero. The distance associated with a given casualty probability is scaled according to the cube root of the yield.[2] The case where several weapons affect a standard location is handled by applying the largest of the casualty probability percentages caused by any of those weapons. The casualty percentage tables are based on the Hiroshima-Nagasaki data.[3] Percentages of mortalities and of nonmortal casualties are computed.

Another phase of the program computes the probable fallout dose at points on the map chosen so that no standard location is more than a mile and a half from a reading. The locations and yields of the weapons and the speed and direction of the winds are taken into account. The basic pattern of fallout distribution is taken to be a semicircle upwind and a half an ellipse downwind, with slight distortion from the effect of wind shear at low wind speeds. The downwind distance is scaled directly with the speed of the wind, and the amount of radioactive material is kept constant by dividing the dose rates by this wind scaling factor. Thus as wind speeds increase the contours grow longer and narrower, and the maximum dose rate in the pattern is reduced. For weapons of different yields, the size of the pattern is scaled according to cloud diameters.[4] This fallout contour model was developed with the advice and assistance of Dr. Lester Machta and Mr. Leo Quenneville, the special projects branch of the U.S. Weather Bureau. The lengths and areas of the contours, and hence the amount of radioactive material distributed, are those developed by the Physical Vulnerability Division, Director of Targets, Assistant Chief of Staff, Intelligence, Headquarters U.S. Air Force.[5] The doses from all weapons near enough to affect a point are added together.

The percentages of the population killed and made ill by the fallout dose are computed, taking into account the shielding of the homes, basements, and other places where the people might take cover.[6] The table of residual factors and poplulation distribution used in the June 3, 1959, computations for the Holifield committee were based on estimates by Mr. Gallagher and Mr. Horton of OCDM of the best protection that might be afforded by moving people into the available structures offering the best protection from radiation. The fallout casualty percentage are computed from the effective biological dose, a concept taking

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[1] "National Location Code." Prepared for Federal Civil Defense Administration by Stanford Research Institute. January 1956.

[2] "The Effects of Nuclear Weapons." Department of the Army Pamphlet No. 39-3. May 1957: p. 96.

[3] "Vulnerability Functions for Civil Defense Damage Assessment Program." Prepared for Federal Civil Defense Administration by Stanford Research Institute. April 1956; pp. 5, 7, 16-20. Secret.

[4] "Close-in Fallout." W. W. Kellogg, R. R. Rapp, and S. M. Greenfield. Journal of Meteorology. February 1957.

[5] "Nuclear Weapons Employment Handbook." Air Force Manual 200-8. HQUSAF; pp. 101-108.

[6] "Effects of Nuclear Weapons," pp. 470-477. "Nuclear Weapons Employment Handbook," p. 125.

into account the ability of the body to recover from some of the radiation to which it is exposed. This dose was defined by a committee of leading radiologists meeting under OCDM auspices on February 20, 1959.

The direct effects mortalities are computed first, then the fallout mortality rate is applied to those surviving. In this way the program avoids counting the same fatality twice. The same procedure is then followed for the nonmortal casualties from direct effects and from fallout.

II.—The second question related to the average radiation dose to D+90 days. The average for all survivors was 110 roentgens, while the average for noninjured survivors was 60 roentgens.

Representative DURHAM. Mr. Chairman, I want to express my appreciation, and I think the country at large should appreciate the fine work you people have done in trying to educate the public.

I would like to ask whether or not we should continue to do something like this on a yearly basis, to try to further bring to the public the important thing that we face. Do you think it should be done annually, semiannually, or how often?

Mr. QUINDLEN. Sir, I think that the people of the United States certainly at least annually would benefit by having the attention of the Senate and the House of Representatives devoted to this as a recognition of the importance and of the facts of life which are here present; and that this is not a scare business but that this is a realistic problem to which all of us must devote a good amount of attention.

Representative DURHAM. That is exactly what this committee has endeavored to do from the beginnings of the first radiation hearings all the way through, to put the facts in print so that the people can know what is before them.

Representative HOLIFIELD. Mr. Quindlen, many of the members of this committee, all of them I would say, have borne a very heavy burden of responsibility in carrying figures like these and similar ones in our heads for a long time. Many of us feel it is time for the American people to help bear the burden of responsibility of the kind of world we live in and try to help solve the problems. They are difficult problems. Maybe there are no solutions. But the composite understanding of the American people, it seems to me, is an adequate source of intellectual resource to solve almost any problem, provided we are given an opportunity.

Mr. QUINDLEN. Sir, as I indicated in my first presentation on Monday morning, it is our firm conviction that if the public is fully informed, it will take the necessary action. This has been demonstrated many, many times in our history.

Representative HOLIFIELD. Thank you.

At this time I would like to insert in the record an article by Hugh Everett III, and George Pugh, of the Institute of Defense Analysis.

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THE DISTRIBUTION AND EFFECTS OF FALLOUT IN LARGE NUCLEAR-WEAPON CAMPAIGNS†

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(Received October 21, 1958)

The purpose of this paper is to provide a simple way of evaluating the consequences of radioactive fallout from a large nuclear-weapon campaign without resorting to detailed map studies. Simple analytic formulas based on numerical data in Rand Memorandum RM-1969 are presented that enable one to make rapid statistical estimates of the distribution of fallout and its effects on a population, as well as the consequences of changing the total delivered yield or the targeting doctrine. The method was checked against a detailed map study, using the same parameters, and was found to be in excellent agreement with its results. A method of optimally distributing weapons among large areas in order to maximize radiation casualties is deduced on the basis of the formulas, and curves are exhibited expressing the casualties produced as a function of total yield delivered. The achievement of optimized attacks does not require a delivery accuracy with probable error less than about a hundred miles. In addition, the formulas are applied to a number of other targeting doctrines, and the resulting curves of casualties versus total delivered yield are presented.

THIS PAPER takes as its point of departure a model analyzed by The Rand Corporation.‡ This model is as follows: Nuclear weapons are dropped uniformly at random into a large area. Each weapon is equally likely to fall at any point in the area, independently of where any of the others may fall. It is further assumed that the weapons burst simultaneously at the surface, that all are of the same yield, and that the area is large compared to the area of contamination of a single weapon.

We shall show that the results of Rand's analysis of this model are adequately summarized by a single simple analytic expression, giving the probability distribution of the integrated dose 24 hours after detonation (the H_r+24 integrated dose) at any point in the area as a function of the yield density (megatons/square mile) delivered in the area.

We then observe that the response function of a population (the fraction of casualties produced as a function of the unshielded dose in roentgens)

† The paper presented here is a mathematical study which was conducted independently by the authors. It does not represent and is not intended to represent official thinking or plans.

‡ S. M. GREENFIELD, "Radioactive Contamination from a Multibomb Campaign," Rand RM-1969, January, 1956.

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can usually be expressed as a simple analytic form over a wide range of conditions. This function is then combined with the fallout distribution function to produce a single formula expressing the expected casualty fraction in a region as a function of the yield density delivered to the region.

Having determined the expected response as a function of delivered yield, we turn our attention to the question of 'optimizing' the distribution of a fixed stockpile in order to maximize radiation casualties. Equations are deduced that relate the yield density to be delivered in each region to the population density in the region, for such an 'optimal' attack.

Finally the formulas are applied to a number of targeting doctrines, namely:

1. Yield density distributed optimally.
2. Yield density proportional to population density.
3. Yield density uniform over entire area under attack.
4. Air-base targeting.

For each of these doctrines, curves are displayed relating expected casualties under various assumptions of population preparedness to the total yield committed.

LIST OF SYMBOLS

H_r = time of weapon burst
$x = H_r$+24-hr integrated dose, roentgens
X = randon variable associated with x
y = natural logarithm of H_r+24-hr integrated dose $y = \ln x$
Y = random variable associated with y, $Y = \ln X$
μ = mean of Y
σ^2 = variance of Y
ζ = mean of X
τ^2 = variance of X
θ = yield density scale factor
D = yield density in neighborhood of a point (megatons/10^4 sq naut mi)
D_0 = that yield density for which $\sigma^2 = \ln 2 = \sigma_0^2$
μ_0 = mean of Y for yield density D_0
$R(x)$ = fraction casualties produced by 24-hr integrated dose x
$\bar{R}(D)$ = fraction casualties produced in region of yield density D
ξ,η = parameters of $R(x)$ depending upon casualty definition and population preparedness
Φ = standard cumulative normal function: $\Phi(y) = \left(1/\sqrt{2\pi}\right)\int_{-\infty}^{y} e^{-x^2/2}\,dx$
χ = dimensionless parameter defined by $\chi = (\mu - \xi)/\sqrt{\sigma^2+\eta^2}$
ρ = population density (people/sq naut mi)
$\Gamma(\rho)$ = population density distribution
A = total area under attack
$D^0(\rho)$ = yield density as a function of population density which maximizes casualties for fixed total yield expended

E = total expected casualties
$\bar{E}$ = average expected casualties per unit area
S = total yield expended in campaign
$\bar{S}$ = average yield density
λ = Lagrange multiplier
ρ_0 = population density cut-off; for optimal attacks regions of population density below ρ_0 are not attacked at all
D^* = the yield density of highest efficiency, i.e., for which $\bar{R}(D)/D$ is a *maximum*; for optimal strikes, no region is attacked with density lower than D^*
$\bar{R}^*$ = fraction casualties produced by D^*: $\bar{R}^* = R(D^*)$

SUMMARY OF RESULTS

Before presenting the detailed arguments we shall give a summary of the final results of this study. These results are as follows:

Fallout Distribution

For a large campaign, in which there is significant overlapping of fallout patterns, the probability distribution of the 24-hr integrated dose x (roentgens) at a particular point, is a *lognormal distribution*. That is, the natural logarithm of the dose, $y = \ln x$, is normally distributed with mean μ and variance σ^2:

$$P(y)\,dy = \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{\frac{-(y-\mu)^2}{2\sigma^2}\right\} dy,$$

where μ and σ^2 depend only on the yield density D (in megatons/10^4 sq naut mi for weapons that are ⅔ fission) delivered in the region of the point:

$$\sigma^2 = \ln(1 + D_0/D),$$
$$\mu = \mu_0 + \tfrac{1}{2}\ln 2 - \tfrac{1}{2}\sigma^2 + \ln(D/D_0),$$

where μ_0 and D_0 are empirical constants.

Response Functions

A response function R expresses the fraction casualties produced in a population as a function of the dose received by the population. It depends both upon the definition of casualty, and upon the condition of the population (such as amount of shelter available, warning time, etc.).

Under a wide range of conditions the response functions are closely approximated by *cumulative normal functions* of the *logarithm*, y, of the H_r+24-hr integrated dose x. That is, if a population has received the total H_r+24-hr dose x, the fraction casualties produced, R, is:

$$R = \Phi[(y-\xi)/\eta],$$

where $\quad y = \ln x \quad$ and $\quad \Phi(z) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} e^{-x^2/2}\,dx,$

and ξ and η are constants depending upon the casualty definition and population condition.

Combined Formula

When the fallout distribution function is combined with the response function, the result is a function $\bar{R}(D)$ expressing the expected casualty fraction $\bar{R}$ in a region as a function of the yield density D delivered in the region:

$$\bar{R}=\Phi[(\mu-\xi)/\sqrt{\sigma^2+\eta^2}].$$

Optimized Attacks

An 'optimal' attack strategy is a function $D^0(\rho)$, the yield density to be delivered to each region as a function of the population density of the region, which maximizes the total casualties for a fixed total yield expenditure. An optimal strategy has the property that there is a certain *cut-off population* density, ρ_0, such that regions of lower population density are not attacked at all, while regions of higher density are always attacked with yield density not less than a certain minimum D^*. In particular, for a strategy $D(\rho)$ to be optimal it must satisfy:

$$D(\rho)=0 \qquad (0\leqq\rho<\rho_0)$$

$$d\bar{R}/dD=(\rho_0/\rho)(\bar{R}^*/D^*) \qquad (\rho_0\leqq\rho\leqq\infty)$$

where

$$\bar{R}^*/D^*=\max_D[\bar{R}(D)/D].$$

These equations define a class of optimal strategies parameterized by the population density cut-off ρ_0. By solving them for a selection of values of ρ_0, and computing the total casualties and yield expended in each case, one arrives at the casualty versus total yield function for optimal attacks.

MATHEMATICAL DEDUCTIONS

WE NOW discuss in detail the derivation and justification of the formulas summarized above.

Fallout Distribution Function

Let us begin by making the assumption (to be tested later) that, for any yield density D, the H_r+24-hr integrated dose at a point is a random variable X which is *lognormally* distributed:

$$P(x)\,dx=(1/x\sigma\sqrt{2\pi})\exp[-(\ln x-\mu)^2/2\sigma^2]\,dx. \qquad (1)$$

Our present task is to determine the dependence of the parameters μ and σ^2 on D. Let us define ζ,τ^2 to be the mean and variance, respectively, of X:

$$\zeta=\int_0^\infty x\,P(x)\,dx, \qquad \tau^2=\int_0^\infty (x-\zeta)^2\,P(x)\,dx. \qquad (2)$$

Then straightforward calculation yields the relations:

$$\zeta = e^{(\sigma^2/2+\mu)}, \qquad \tau^2 = e^{2\mu}\,[e^{2\sigma^2} - e^{\sigma^2}] = \zeta^2\,[e^{\sigma^2} - 1], \tag{3}$$

for which the inverse relations are:

$$\sigma^2 = \ln(\tau^2/\zeta^2 + 1), \qquad \mu = \ln(\zeta^2/\sqrt{\zeta^2+\tau^2}) = \ln\zeta - \tfrac{1}{2}\,\sigma^2. \tag{4}$$

Now suppose that for a single attack, of a particular yield density, the mean and variance of X are ζ and τ^2 respectively. Then if we make, instead of a single attack, θ attacks, the new mean and variance will be given by:

$$\zeta' = \theta\zeta, \qquad \tau'^2 = \theta\tau^2, \tag{5}$$

according to the laws for sums of independent random variables. (The random variable X' for the multiple attack is simply the sum of the corresponding variables X for each single attack.) But θ independent strikes are completely equivalent to a single strike of density θ times greater than the density of the original attack. Therefore, equations (5) express the general density scaling law, when θ represents the ratio of the densities and is an integer. Furthermore, since this law must hold for all ways of decomposing a strike of a given density into substrikes, we can conclude that it holds for all real numbers θ as well as for integers.

Equations (5), which express the laws of scaling the mean and variance of X for different yield densities, together with the relations (3) and (4), imply the following scaling laws for μ and σ:

$$\sigma'^2 = \ln\left(\frac{e^{\sigma^2} - 1 + \theta}{\theta}\right), \qquad \mu' = \mu + \tfrac{1}{2}\,(\sigma^2 - \sigma'^2) + \ln\theta, \tag{6}$$

where $\theta = D'/D$.

We must now comment upon a mathematical difficulty of this scheme. While we have correctly deduced the scaling laws for μ and σ under the *assumption* that we always have a lognormal distribution, using the laws for the addition of random variables, it is unfortunately *not* true that the sum of two lognormally distributed random variables is lognormally distributed. (The convolution of two lognormal distributions is not lognormal). However, over the range of interest in our case the discrepancies are sufficiently small that they may be safely ignored, and it is a good approximation to regard all of our distributions as lognormal.

Let us now, for convenience, define a constant D_0 to be that yield density (as yet unknown) such that $\exp\sigma_0^2 = 2$ for the corresponding σ, and let μ_0 denote the corresponding value of μ. Then (6) can be rewritten in the form:

$$\sigma^2 = \ln(1 + D_0/D), \qquad \mu = \mu_0 + \tfrac{1}{2}\ln 2 - \tfrac{1}{2}\,\sigma^2 + \ln(D/D_0). \tag{7}$$

These equations contain only two constants, μ_0 and D_0, which must be evaluated empirically, and we have succeeded in our endeavor to determine the dependence of μ and σ upon D.

In order to determine the values of μ_0 and D_0, a number of points were read from Rand RM-1969 (Fig. 1) for each of seven selected values of D(5, 10, 15, 20, 30, 40, and 50 meg/10^4 sq naut mi), and the log dose versus fractional coverage plotted on probability paper. Straight lines were visually adjusted through these points, for each D, and the resulting means and variances read off. By using the first of equations (7), a value of D_0

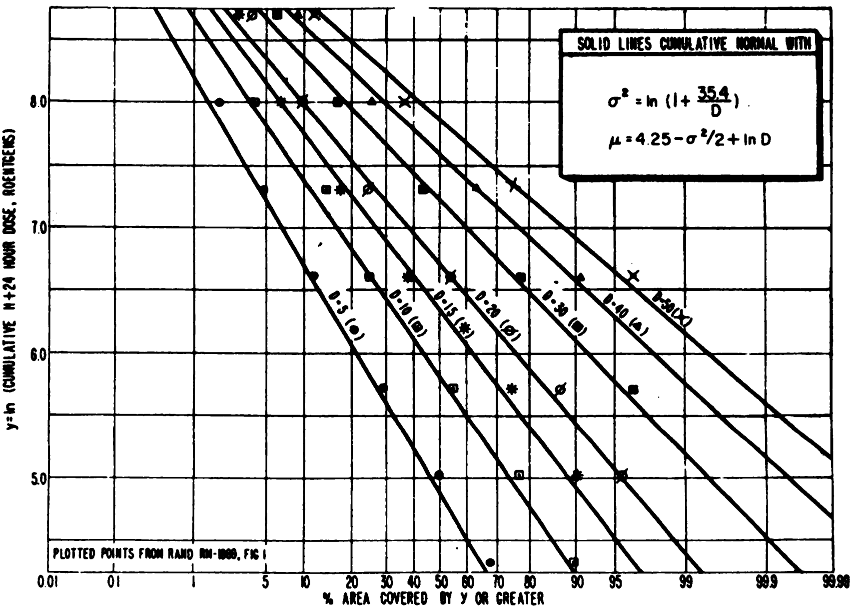

Fig. 1. Fraction of area covered by doses for which the natural logarithm is greater than y. Curves are plotted for several values of the yield density, D, which is indicated in megatons per (100 naut mi)^2.

was computed for each value of D, and an appropriate average selected for best fit in the region $D = 10$ to 20. The resulting choice was:

$$D_0 = 35.4 \text{ megatons}/10^4 \text{ sq naut mi.} \tag{8}$$

Having decided upon D_0, μ_0 was evaluated by the second of equations (7), and again an appropriate average selected:

$$\mu_0 = 7.47. \tag{9}$$

The resulting equations (from 7) are then:

$$\sigma^2 = \ln(1 + 35.4/D), \qquad \mu = 4.5 - \tfrac{1}{2}\sigma^2 + \ln D. \tag{10}$$

Figure 1 shows the theoretical fractional coverage curves based upon equations (10), with points from Rand RM-1969 plotted to show the adequacy of the fit. Figure 2 graphically depicts equations (10), from which values of μ and σ^2 may be read off for any value of yield density D.

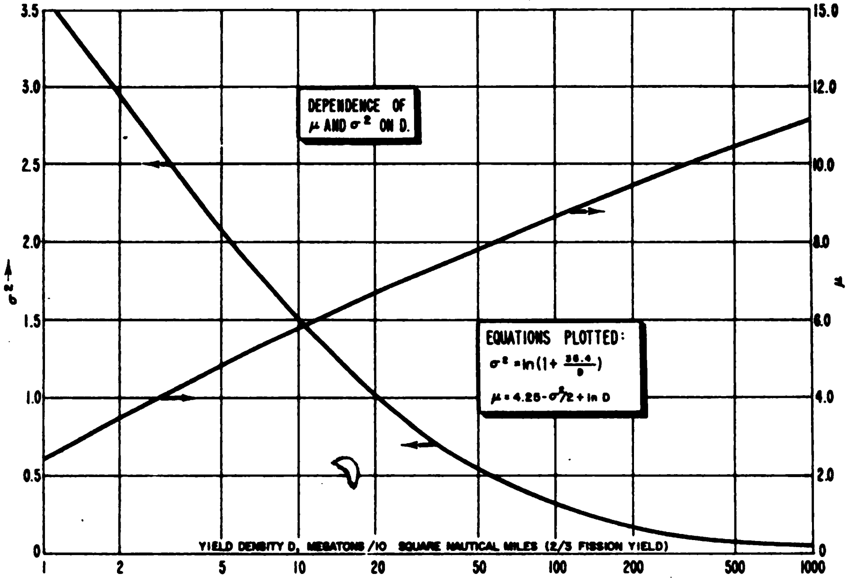

Fig. 2. Curves showing the computed dependence of μ and σ^2 on yield density, D.

Response Functions

Let us now assume that the *response function*, R, for a population has the form of a cumulative normal function of the logarithm of the $H+24$-hr integrated dose, y:

$$R(y) = \Phi[(y-\xi)/\eta], \tag{11}$$

where R is the casualty fraction, ξ and η are constants depending upon the condition of the population and definition of casualty, and Φ is the standard cumulative normal function defined by:

$$\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{\infty}^{z} \exp(-\tfrac{1}{2}\,\omega^2)\, d\omega. \tag{12}$$

If equation (11) is plotted on *probability paper* it is a straight line. Thus, the assumption that response functions are represented by (11) can

be tested by simply plotting log(H_r+24-hr dose) against *casualty fractions produced* for *known* response functions, and observing whether or not the points are fitted by a straight line.

To illustrate the fit of arbitrary response functions to the lognormal form we have chosen two sets of time-average-shielding factors that are based on behavior patterns chosen by some social scientists for two particular situations that were under consideration. The first behavior pattern (called the 'unprepared case') is intended to represent the behavior and consequent average shielding which might be obtained by an unprepared population given only a few hours warning of attack. The 'prepared case' is intended to represent the time-average-shielding which might be obtained by a population given six-months alert to prepare and build shelters.

The original assumptions were based on consideration of both the available shielding and the fraction of time the population might be expected to take advantage of the shielding. However, we will list here only the time-average-shielding.

The time-average-residual numbers† for both cases are given below:

Unprepared		*Prepared*	
Percent population	Residual number	Percent population	Residual number
52	0.50	13	0.50
6	0.40	8	0.20
7	0.29	5	0.18
31	0.24	26	0.15
2	0.07	7	0.07
2	0.017	30	0.038
		11	0.016

These numbers are based on the behavior of large groups that were given identical behavior. The numbers are quite arbitrary, and certainly do not have any simple analytic form. However, the response functions calculated from these behavior patterns are so smoothed by statistical variations in biological response that the results fit quite acceptably to the lognormal curve. Both casualties and deaths were computed for sixty days after initial exposure.

Figure 3 shows the result of plotting these data on probability paper, with the natural logarithm of the dose as ordinate. The straight lines which are drawn through the plotted points give a remarkably good fit, justifying the assumption that equation (11) represents response functions.

† Residual numbers are a decimal representation of the fraction of the unshielded dose that reaches the personnel in question.

The parameters ξ and η^2 were determined from Fig. 3, with the following results:

Case	*Response*	ξ	η^2
Unprepared	Total casualties	6.00	0.34
	Deaths	6.62	0.34
Prepared	Total casualties	7.32	1.32
	Deaths	8.01	1.32

(13)

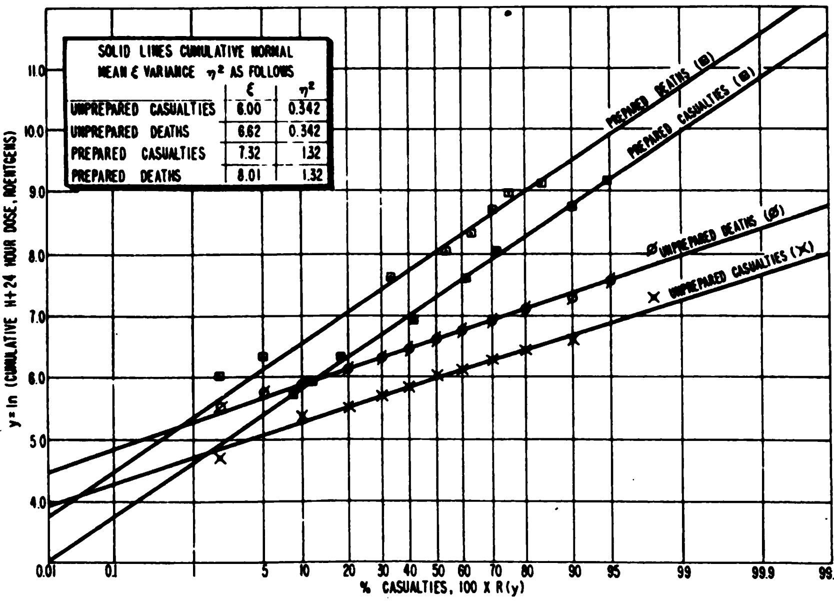

Fig. 3. Total population response at 60 days plotted against the natural logarithm of the unshielded dose.

Combined Formula

From equation (1) we can deduce the probability distribution of y:

$$P(y)dy = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(y-\mu)^2}{2\sigma^2}\right] dy, \qquad (14)$$

so that the log-dose is normally distributed, with mean μ and variance σ^2 given by (10).

Since we also have the response function $R(y)$, given by (11), we can compute the over-all expected casualty fraction $\bar{R}$ (casualty probability):

$$\begin{aligned}\bar{R} &= \int_{-\infty}^{\infty} R(y)\,P(y)\,dy \\ &= \int_{-\infty}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(y-\mu)^2}{2\sigma^2}\right] \Phi\left(\frac{y-\xi}{\eta}\right) dy = \bar{R}(\mu,\sigma,\xi,\eta).\end{aligned} \tag{15}$$

A little manipulation greatly simplifies this equation. Writing (15) in full we have:

$$\bar{R} = \int_{-\infty}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(y-\mu)^2}{2\sigma^2}\right] \int_{-\infty}^{(y-\xi)/\eta} \frac{1}{\sqrt{2\pi}} \exp\left[\frac{-\nu^2}{2}\right] d\nu\, dy. \tag{16}$$

By making the transformations $\omega = (y-\mu)/\sigma$ and $\alpha = \nu - (\sigma\omega + \mu - \xi)/\eta$, interchanging the order of integration, and carrying out the integration over ω we obtain:

$$\bar{R} = \int_{-\infty}^{0} \frac{1}{\sqrt{2\pi(1+\sigma^2/\eta^2)}} \exp\left[\frac{-(\eta\alpha+\mu-\xi)^2}{2(\eta^2+\sigma^2)}\right] d\alpha, \tag{17}$$

and a final transformation $\Psi = (\eta\alpha + \mu - \xi)/\sqrt{\eta^2+\sigma^2}$ gives:

$$\bar{R} = \int_{-\infty}^{(\mu-\xi)/\sqrt{\sigma^2+\eta^2}} \frac{1}{\sqrt{2\pi}} \exp(-\tfrac{1}{2}\Psi^2)\, d\Psi = \Phi\left(\frac{\mu-\xi}{\sqrt{\sigma^2+\eta^2}}\right). \tag{18}$$

Thus, our final formula for the expected casualty fraction takes on the simple form

$$\bar{R}(\mu,\sigma,\xi,\eta) = \Phi[(\mu-\xi)/\sqrt{\sigma^2+\eta^2}] = \Phi(\chi), \tag{19}$$

which is a function of the single dimensionless parameter χ:

$$\chi = (\mu-\xi)/\sqrt{\sigma^2+\eta^2}. \tag{20}$$

Equation (19), together with relations (10), then summarizes the expected casualty fraction as a function of the yield density of the attack D, and the constants ξ, η, of the population condition, given by (13).

The expected response $\bar{R}$ is shown as a function χ in Fig. 4, which is a graph of equation (19).

Finally, the expected response is plotted directly as a function of yield density in Fig. 5, which represents the basic results to be used in the remainder of the paper.

Optimal Distribution of Weapons

Now that we have determined the casualty fraction as a function of yield density for prescribed population conditions and casualty definitions, a natural question arises: For a given population, distributed geographi-

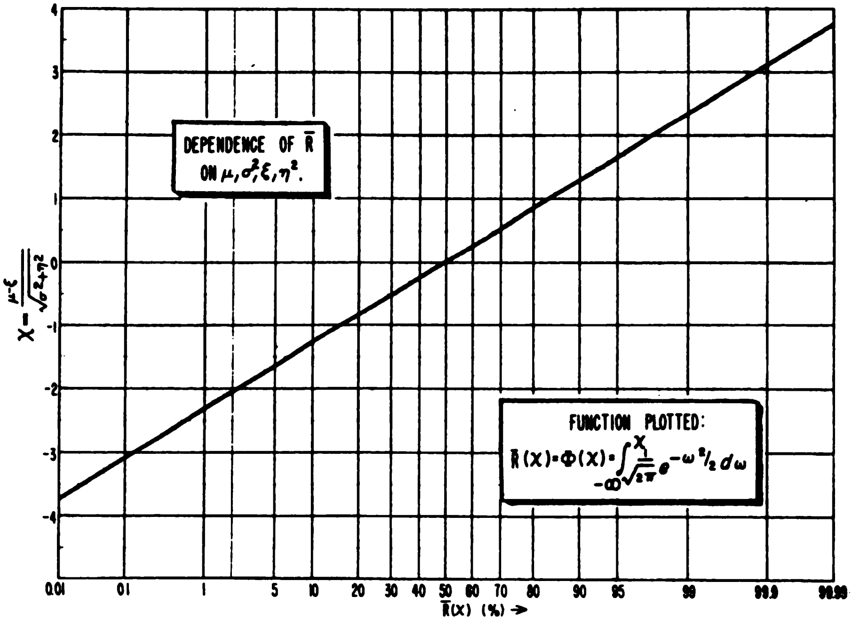

Fig. 4. Dependence of total casualty fraction $\bar{R}(\chi)$ on the dimensionless parameter χ.

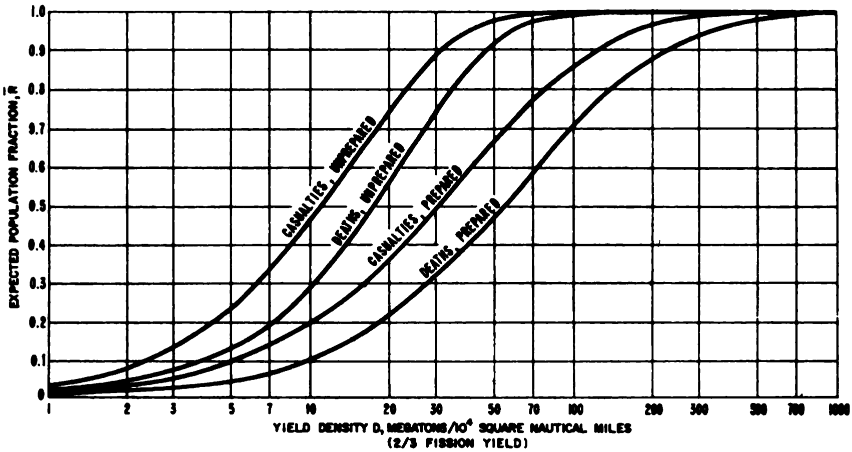

Fig. 5. Expected population response at 60 days as a function of yield density, *D*, of attack.

cally in some known manner, how should one distribute a fixed number of weapons in order to maximize the expected casualties?

The population distribution can be represented by a population density function, ρ, (a function of geographical position), for which the value at a particular position is taken to be the average population density of some suitably chosen neighborhood at the point.

Our problem is, therefore, to determine a function $D(\rho)$, the yield density to be delivered in each region as a function of the population density, which maximizes the expected casualties subject to the constraint that the total megatonnage delivered is a fixed quantity S.

Let us now define a function $\Gamma(\rho)$, to be called the *population density distribution*, such that the fraction of area contained in the region whose population density is between ρ and $\rho+d\rho$ is $\Gamma(\rho)\,d\rho$. Letting A stand for the total area under attack, we have that for any choice of $D(\rho)$ the total expected casualties produced is:

$$E=\int_0^\infty \bar{R}[D(\rho)]\,\rho A\,\Gamma(\rho)\,d\rho, \tag{21}$$

or, normalizing out the total area:

$$\tilde{E}=E/A=\int_0^\infty \bar{R}[D(\rho)]\,\rho\,\Gamma(\rho)\,d\rho. \tag{22}$$

On the other hand, the total yield expended in the campaign is easily seen to be:

$$S=\int_0^\infty D(\rho)\,A\,\Gamma(\rho)\,d\rho, \tag{23}$$

or, again normalizing $$\tilde{S}=\frac{S}{A}=\int_0^\infty D(\rho)\,\Gamma(\rho)\,d\rho. \tag{24}$$

Our task is therefore to choose $D(\rho)$ in order to maximize $\tilde{E}$ subject to the constraint (24). Introducing a Lagrange multiplier λ, in the usual manner, reduces the problem to maximizing the single (unconstrained) expression:

$$\begin{aligned}\tilde{E}&=\int_0^\infty \bar{R}(D)\,\rho\,\Gamma(\rho)\,d\rho+\lambda\left[\tilde{S}-\int_0^\infty D(\rho)\,\Gamma(\rho)\,d\rho\right]\\ &=\int_0^\infty [\bar{R}(D)\,\rho-\lambda D]\,\Gamma(\rho)\,d\rho+\lambda\tilde{S}.\end{aligned} \tag{25}$$

Before proceeding, we list several considerations that will be pertinent in the subsequent derivation:

1. The following properties of our functions are easily verified: D is nonnegative, $\bar{R}(D)$ is monotone increasing, $\bar{R}(0)=0$, $\bar{R}(\infty)=1$, $d\bar{R}/dD$ is nonnegative, bounded above, and $[d\bar{R}/dD]_{D=0}=0$.

2. It is obvious, but can be rigorously proven that if $D(\rho)$ is optimal, then it must be monotone increasing with ρ. (It never pays to put the higher yield densities in areas of lower population density.)

3. Since $D(\rho)$ is, in effect, a freely chosen strategy it may very well be discontinuous.

We proceed by calculating the variations produced by a variation of δD in D:

$$\delta\bar{E}=\int_0^\infty\left[\rho\frac{d\bar{R}}{dD}-\lambda\right]\delta D\,\Gamma(\rho)\,d\rho. \tag{26}$$

Now we must notice a fact peculiar to our case, namely, that the nonnegativity of D implies that the variation δD is not *arbitrary* in case D itself is zero, but is constrained to positive values (while if $D>0$, δD can have arbitrary sign, of course). Now the necessary condition for maxima is simply that $\delta\bar{E}\leqq 0$ (not the more restrictive $\delta\bar{E}=0$), and we see from (26) that, to satisfy this criterion, either

$$D=0 \qquad \text{or} \qquad \rho\, d\bar{R}/dD=\lambda, \qquad (0\leqq\rho\leqq\infty) \tag{27}$$

since for $D=0$ the integrand is *negative* (λ nonnegative, $d\bar{R}/dD=0$) and δD is restricted to positive values, which produce negative variations in $\bar{E}$, while for $D>0$, δD is arbitrary and the integrand must vanish.

But these conditions (27) cannot be met by a continuous function $D(\rho)$, because $d\bar{R}/dD$ is nonnegative and bounded above and $\lim_{D\to 0} d\bar{R}/dD=0$, so that (27) cannot have any solution involving arbitrarily small values of D, and $D(\rho)$ must possess a *jump discontinuity* from zero at some point ρ_0.

Therefore, there exists a ρ_0 such that $D(\rho)$ is discontinuous at ρ_0, and satisfies:

$$\begin{aligned} D&=0, && (0\leqq\rho<\rho_0)\\ \rho d\bar{R}/dD&=\lambda. && (\rho_0\leqq\rho\leqq\infty) \end{aligned} \tag{28}$$

But now we have introduced a new parameter ρ_0, which must itself be chosen so as to maximize $\bar{E}$, which can now be written:

$$\bar{E}=\int_{\rho_0}^\infty[\bar{R}(D)\,\rho-\lambda D]\,\Gamma(\rho)\,d\rho+\lambda\bar{S}. \tag{29}$$

From which we compute:

$$d\bar{E}/d\rho_0=-\Gamma(\rho_0)\,\{\bar{R}[D(\rho_0)]\,\rho_0-\lambda\,D(\rho_0)\}. \tag{30}$$

And applying the condition that $d\bar{E}/d\rho_0=0$, we obtain the final condition for our optimal program:

$$\bar{R}[D(\rho_0)]/D(\rho_0)=\lambda/\rho_0. \tag{31}$$

We can use (31) to evaluate λ in (28), so that the conditions for an optimum distribution $D(\rho)$ become:

$$\begin{aligned} d\bar{R}/dD &= (\rho_0/\rho)\{\bar{R}[D(\rho_0)]/D(\rho_0)\}, && (\rho_0 \leqq \rho \leqq \infty) \\ D &= 0. && (0 \leqq \rho < \rho_0) \end{aligned} \qquad (32)$$

And we notice that at ρ_0, (32) implies that

$$d\bar{R}/dD = \bar{R}/D \quad \text{at} \quad \rho = \rho_0, \qquad (33)$$

which is the condition that $\bar{R}/D$ is a *maximum*, which we shall denote by:

$$\bar{R}^*/D^* = \max_D [\bar{R}(D)/D]. \qquad (34)$$

Summarizing (32), (33), (34), we can state the rules for the optimum distribution $D(\rho)$ as follows:

For every choice of a population density cut-off ρ_0 there is an optimal distribution $D(\rho)$ which has the property that $D(\rho)$ is zero for all densities less than ρ_0, while areas of the critical density ρ_0 are attacked with yield density D^* (producing the maximum value of $\bar{R}/D$—the highest 'efficiency'), and for population densities $\rho > \rho_0$, $D(\rho)$ is chosen to satisfy $d\bar{R}/dD = (\rho_0/\rho)\, \bar{R}^*/D^*$. Symbolically,

$$\begin{aligned} D &= 0, && (0 \leqq \rho < \rho_0) \\ d\bar{R}/dD &= (\rho_0/\rho)\bar{R}^*/D^*, && (\rho_0 \leqq \rho \leqq \infty) \end{aligned} \qquad (35)$$

where $\bar{R}^*/D^*$ is given by (34).

Equations (35) give optimal distributions for each value of population density cut-off ρ_0. For each choice of ρ_0 the optimal distribution may be computed, and from it, the casualties E and the total invested yield S. By performing this calculation for a number of choices of ρ_0, the general dependence of E on S for optimal distribution of weapons is obtained.

In order to illustrate the dependence of yield density on population density for an optimized campaign, we shall carry out the optimization of *deaths* in the *unprepared* case, and, for comparison, in the prepared case as well.

From equation (35) we see that

$$\rho/\rho_0 = (\bar{R}^*/D^*)/(d\bar{R}/dD). \qquad (36)$$

The function $d\bar{R}/dD$, as a function of D, can be determined by differentiation of equations (19) and (10) with the appropriate parameters from (13) for the deaths in each case. The maximum value of $\bar{R}/D$, $\bar{R}^*/D^*$, is then determined as the point where $d\bar{R}/dD = \bar{R}/D$, and occurs at about $D^* = 14$ megatons/10^4 sq naut mi for the unprepared case and at $D^* = 23$ megatons/10^4 sq naut mi for the prepared case.

Having determined the right-hand side of (36) as a function of D one is able to make a plot of ρ/ρ_0 vs. D for optimal distributions. This plot is presented for the present cases in Fig. 6.

To use Fig. 6 one first selects a population density cut-off, ρ_0. The optimal distribution of weapons is then to place *no* weapons in regions of population density less than ρ_0, and in regions of higher population density, $\rho > \rho_0$, to place them with density given by Fig. 6. It should be noted that

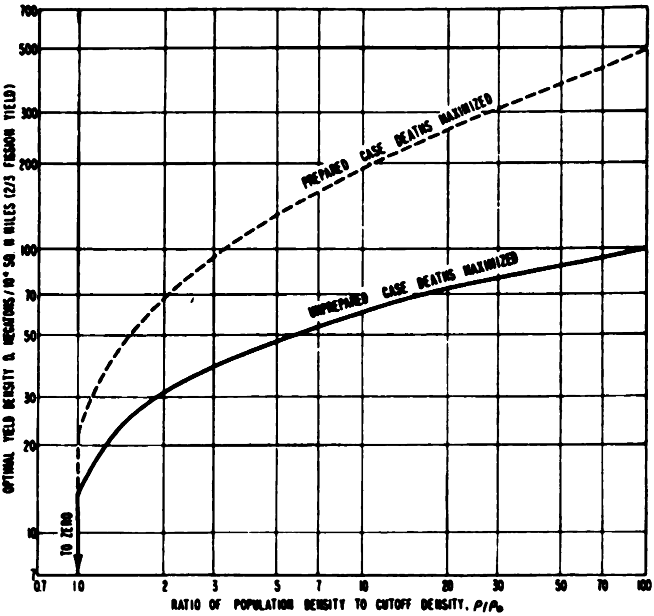

Fig. 6. Yield density vs. population density for 'optimal' campaigns.

no region is ever attacked with yield density of less than $D^* = 14$ megatons/ 10^4 sq naut mi for maximum deaths (unprepared case) campaigns (twenty-three for the prepared case).

Given the distribution of weapons for the optimal campaign arising from a particular choice of ρ_0, it is necessary to calculate both the total casualties (by applying the Fig. 5 to each region) and the total yield expended. By performing this calculation for a number of selections of ρ_0, one can make a direct plot of casualties produced versus total yield expended for optimal campaigns.

ILLUSTRATIVE EXAMPLES

WE SHALL now apply the formulas developed in the previous sections to a number of concrete cases to illustrate the usefulness of the methods.

We shall exhibit response curves (casualty fractions) as a function of total delivered yield for the entire population of the U.S.A. under various assumptions about targeting doctrine and the degree of preparation of the population.

Two sets of shielding factors were used. The first, or unprepared case, was chosen by social scientists to be representative of the shelter which might be used by an untrained populace given emergency instructions to remain under shelter after attack. The prepared case represents a behavior which might exist in a well-trained population given six months to build shelters on an emergency basis. The two cases are chosen to indicate the sensitivity of the results to changes in shielding and exposure patterns which can result from civilian defense measures.

The different targeting philosophies that we shall consider here are:

1. Density of drop optimized (in accordance with the methods discussed) to produce maximum radiation deaths.
2. Density of drop proportional to population density. (A general attack on production, transportation, and communication facilities would probably coincide closely with this case.)
3. Density of drop uniform over entire country.
4. Air-base targeting.

In order to calculate casualties for a particular type of strike we divide the total area into sub-areas receiving different yield densities. The formulas are then used to obtain the percentage response for each area to its corresponding yield density.

In our particular case, the United States was treated as forty-eight separate states, except that New York was broken ⅔, ⅓ by area into an upper and lower New York State.

Strictly speaking, the compiled results correspond to a random drop of weapons in each sub-area. They therefore indicate the results that can be obtained by a delivery system which allows one to hit a chosen state without more accurate specification of the impact point. This is roughly comparable to a probable delivery error of about 100 miles.

DISCUSSION OF VARIOUS TARGETING DOCTRINES

Optimized Drop

Figures 7 and 8 show the results of an optimized drop. The calculation is based on the distribution of population in the forty-eight states. The resulting casualty curves are those that can be expected with a delivery mechanism having a probable delivery error of about one hundred miles.

It is not possible to optimize more than one quantity at a time. In Fig. 7 we optimized deaths in the unprepared case. The remaining curves

are not optimized but show the expected casualties that would occur in the other cases when the attack is optimized for unprepared deaths. For comparison, Fig. 8 shows the result of optimizing for the prepared deaths.

It is worth remarking that the optimized drop strategy has the peculiar

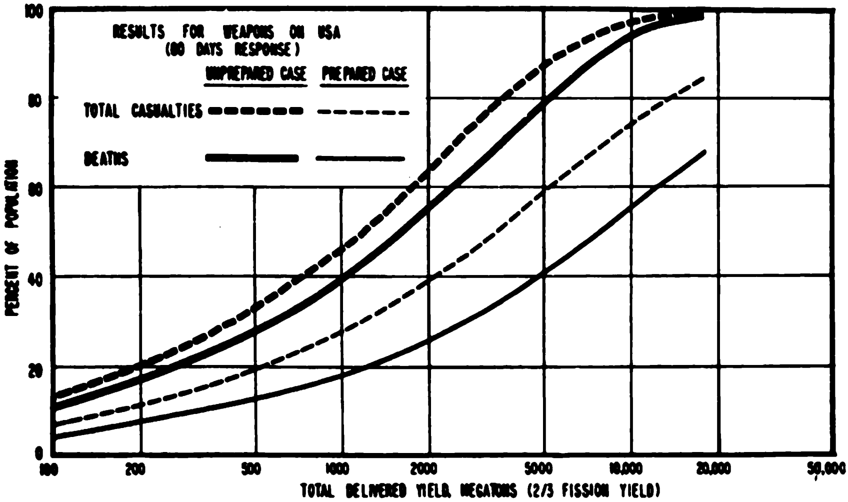

Fig. 7. Population response in the United States resulting from 'optimal' attacks designed to *maximize deaths in an unprepared population.*

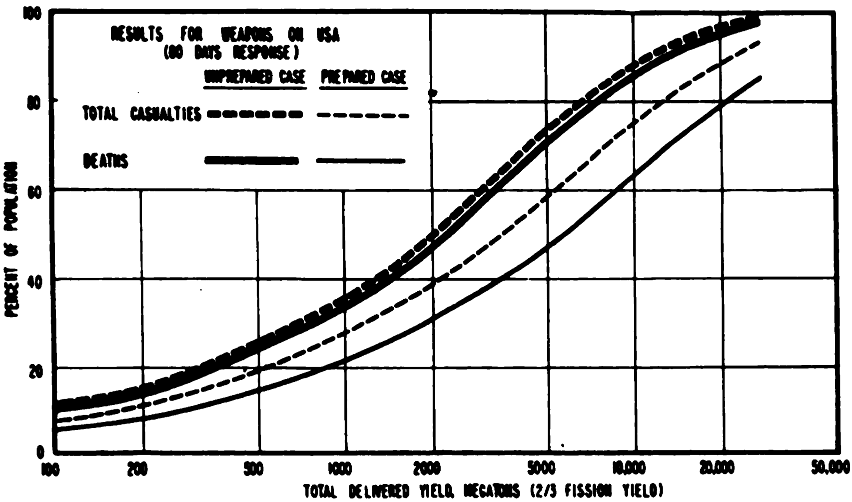

Fig. 8. Population response in the United States resulting from 'optimal' attacks designed to *maximize deaths in a prepared population.*

characteristic that weapons are dropped *only* in areas of high population density. It is therefore quite an unlikely strategy since any strategic point in areas of low population density would be ignored if the procedure were followed to the letter. On the other hand, some increase in casualties above the 'optimized' case would be obtained by using a small CEP and consistently targeting on cities or slightly upwind of them.

The Proportional Drop

This case (Fig. 9) is of interest because many installations of military importance are distributed in a way that resembles the population dis-

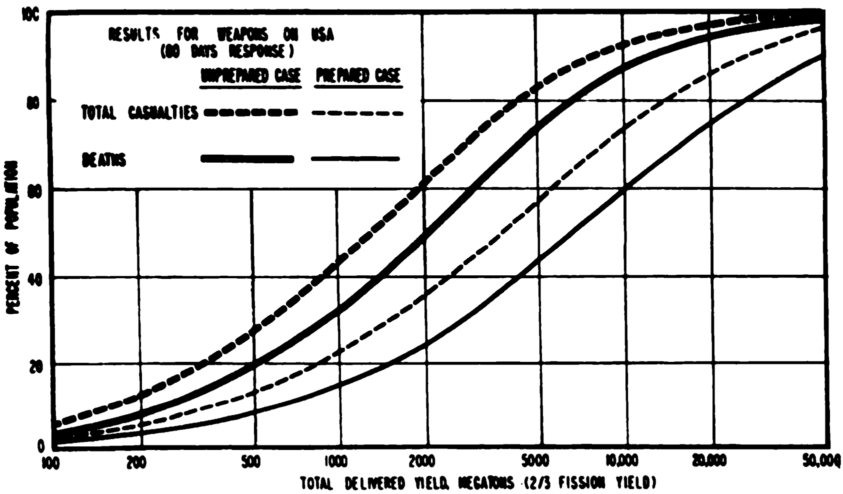

Fig. 9. Population response in the United States resulting from attacks in which the delivered *yield density is proportional to the population density.*

tribution. Air attack on such facilities will probably produce results comparable to those obtained in this case.

Uniform Drop

This case (Fig. 10) is trivial and involves only the multiplication of the yield densities of Fig. 5 by the total area of the country. No claim is made for realism in this doctrine, but it is useful to see how sensitive the results are to extremes in targeting doctrine. This corresponds to the extreme of not targeting at all. It is not, however, a lower limit. It is possible to minimize casualties by dropping all weapons at one point where the population density is minimum.

It is interesting to note that for extremely large-yield campaigns the

uniform drop becomes actually more efficient than the proportional. This is because for high-yield attacks the proportional drop continues to use weapons where everyone is already dead.

Of course, for all values of the total yield, an optimized program must remain above all other programs.

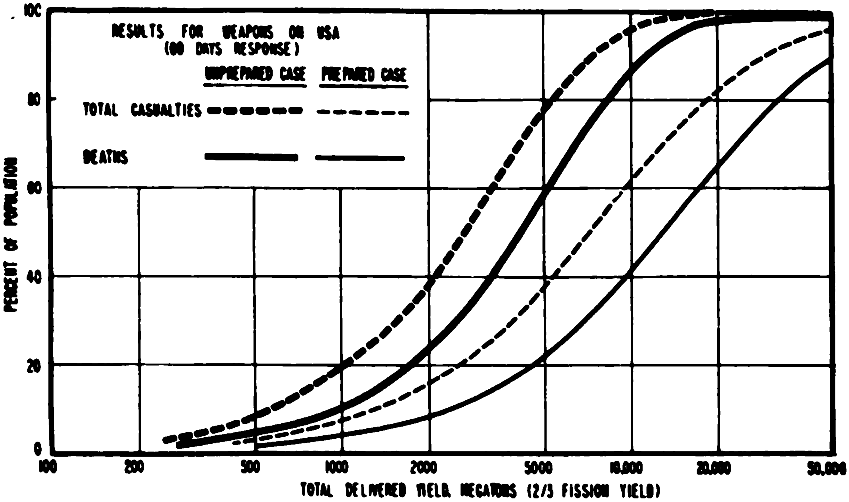

Fig. 10. Population response in the United States resulting from attacks in which the *yield density is uniform over the entire country.*

Air-Base Targeting

The curves calculated for weapons delivered to United States air bases in this example (Fig. 11) assume the same allocation of yield to each SAC base, and one-half that allocation to other major military air bases.

Casualties in this campaign turn out to be even lower than in the uniform drop case. This reflects the fact that SAC bases are generally located in areas of low population density.

The casualties and deaths (prepared and unprepared) obtained in a detailed map study of a similar campaign served as a check of the method. The discrepancies between this method and the map study of the same campaign did not exceed 1 per cent of the population. This agreement is no check of the parameters of either study since the same assumptions about shielding, biological response, and fallout area per weapon went into both studies. It is, however, a check on the random drop model in the various sub-areas.

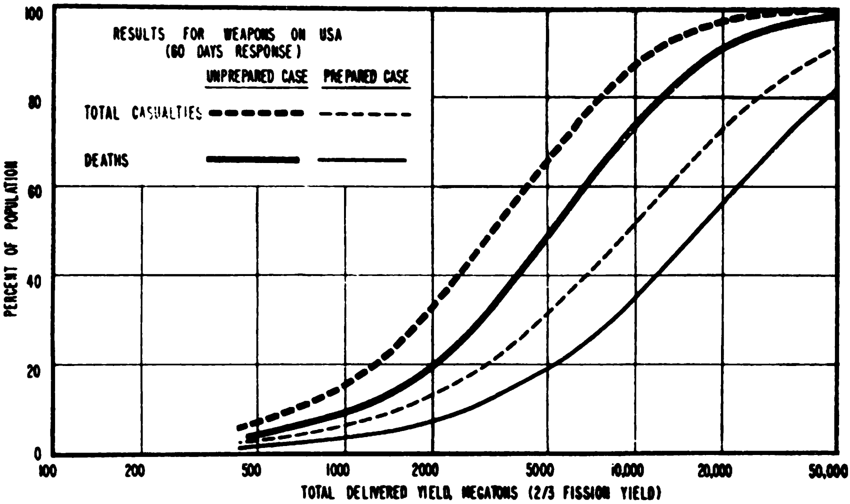

Fig. 11. Population response in the United States resulting from attacks in which the *yield density is proportional to the distribution of military airbases.*

COMPARISON WITH U.S.S.R.

THE CURVES in Figs. 12 and 13 illustrate the sensitivity of the results to different target complexes. Figure 12 is a comparison of the curves for unprepared deaths in the U.S.A. for the four targeting doctrines discussed previously. Figure 13 shows the result of the same type of calculations using the same shielding factors in the U.S.S.R. The somewhat smaller percentage fatalities for a given yield in the U.S.S.R. reflects both the larger population and the lower population density. The effect of the vast empty area of Siberia is of course particularly evident in the results of the uniform drop. For this calculation the U.S.S.R. was broken into twenty-six roughly homogeneous sub-areas, each composed of one to eighteen oblasts and containing 5 to 20 million people.

APPLICABILITY OF THE FORMULAS

THE METHOD presented here provides a comparatively easy and versatile tool for rapidly estimating the effects of fallout in large campaigns. It has the added advantage that it is based upon analytic formulas, so that any future changes in the knowledge of radiation distributions, biological response, or population shielding factors, can be easily incorporated.

It has been our experience, on several occasions, that when a new targeting doctrine was presented it was possible to prepare a new set of results

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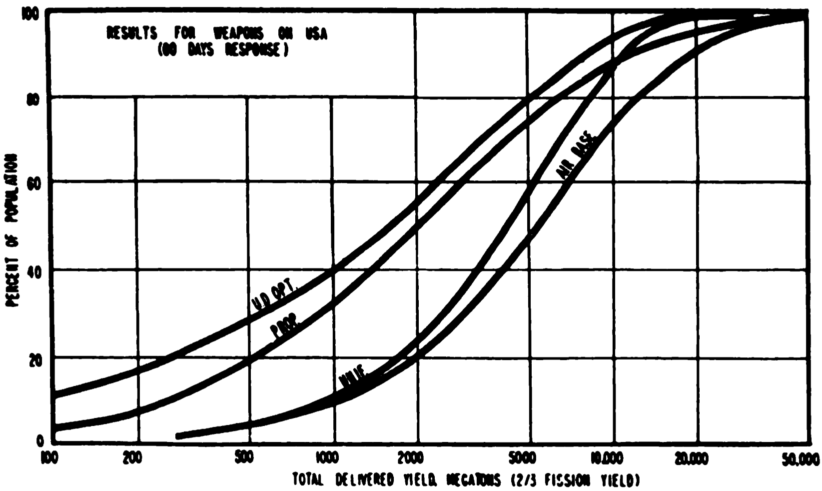

Fig. 12. Comparison of deaths in an 'unprepared' population in the United States for different targeting doctrines: *U.D.OPT.*, 'optimal' distribution of yield-density to maximize deaths in the unprepared population; *PROP.*, yield density proportional to population density; *UNIF.*, yield density uniform in entire country; *AIR BASE*, yield density proportional to the distribution of military airbases.

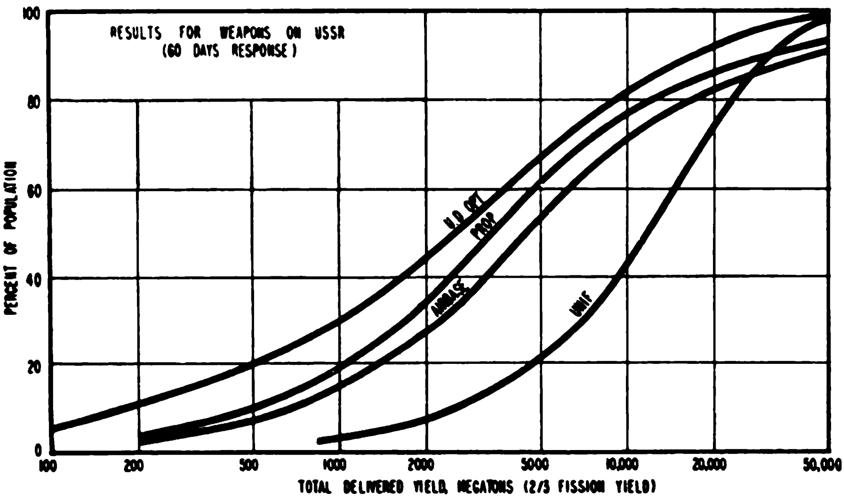

Fig. 13. Comparison of deaths in an unprepared population in the U.S.S.R. for the same targeting doctrines shown in Fig. 12.

in a matter of several hours—not merely for one intensity of attack but for all force levels.

It is, however, *essential* that certain precautions be observed by anyone attempting to apply the methods and results of this memorandum:

1. The methods should only be applied to *large* campaigns (against large areas of the size, say, of the U.S.A., U.S.S.R., Europe, etc.; and total yields in excess of several hundreds of megatons). Only for such campaigns do the statistics allow fairly reliable conclusions without excessive variability, while at the same time minimizing the errors due to edge effects at the boundary of the area under attack.

2. Strictly speaking, this calculation only accounts for *total radiation casualties at about 60 days*. In the model there are *no blast effects whatsoever*. However, almost all actual blast casualties will occur in regions of very high radioactive contamination, and will hence be counted as radiation casualties by this procedure. The results of the method therefore closely approximate the expected *total casualties from all causes*. Finally, it must be pointed out that the total casualties at 60 days may not be indicative of the ultimate casualties. Such delayed effects as the disorganization of society, disruption of communications, extinction of livestock, genetic damage, and the slow development of radiation poisoning from the ingestion of radioactive materials may significantly increase the ultimate toll.

3. The technique described here is based on the concept of a random drop of weapons. It is therefore not appropriate to use it where there is a strong correlation between aiming points and population centers. However, unless the correlation is very strong the error that results from doing so is surprisingly small. In one case, which was considered where one 20 MT weapon was assigned to each of the first N largest cities of the U.S.A., the discrepancy was not great for the yields in excess of 1000 megatons. However, for such campaigns it is much better procedure to calculate the expected casualties in the targeted cities separately. These casualties are then removed from the population and the fraction of casualties expected in the remaining population can then be computed as before.

It should be emphasized that the procedure cannot be used to predict casualties in any individual city. The area casualties predicted are 'expected' values on the basis of a random distribution of wind. On the other hand, it is impossible to predict the spatial distribution of fallout by any known method without accurate weather data at all altitudes. It seems likely that a statistical treatment is all that can be achieved by any method when actual weather conditions are not known.

4. The estimated effects are sensitive to the assumed biological response and shielding factors. The formulas should not be used without an investigation to determine appropriate shielding factors.

The response used here for the unprepared case corresponds roughly to a median, residual number of 0.40 where two-thirds of the residual numbers lie between 0.60 and 0.25; in the prepared case, the mean residual number used was about 0.11 and two-thirds of the residual numbers lie between 0.30 and 0.04. For the purpose of the original calculation, it was assumed that all fallout reached the ground at H_r+6 hours after burst. The response was converted to a response in terms of the integrated 24-hr dose using the same assumption. In order to use a

different set of assumptions it is only necessary to compute the population response as a function of the integrated 24-hr dose for a series of unshielded dose levels. The computed response is then fitted to the lognormal response curve as was done in this case.

On the other hand, the shielding factors can be altered in rough computation simply by selecting different logarithmic means and variances. It is worth remembering that, in order to achieve large average shielding factors, personnel must remain in the shield a high percentage of the time. For instance, to get an average effective residual number of 0.01 a person in a perfect shelter could emerge from it only 1 per cent of the time. Because this method is based on analytic formulas, in which the population response is represented, it is a simple matter to change population response to encompass new data.

All other sources of error in the present approach are swamped by the uncertainty of these population-shielding parameters, an uncertainty which exists to the same degree in all fallout effects studies. Therefore, we feel that this method, with its considerable advantages in simplicity and speed of application, can provide answers that are as reliable as the more detailed studies for the large area campaigns to which it is applicable.

5. It was assumed in this treatment that all weapons were *surface burst*. If it is desired to apply the method to campaigns that have air bursts, these *must not be counted* for these local fallout estimates. Note that in this case, the remarks of 2 to the effect that the method also produces a fairly good estimate of total casualties (including blast) are *no longer applicable*. The blast and other direct effects of the air-burst weapons must be treated separately.

6. When applying the method to a campaign in which the weapons are not distributed uniformly over the entire area of attack, the area must be partitioned into sub-areas that have roughly homogeneous weapon distributions. However, these sub-areas should still be sufficiently large that several weapons are targeted in each, and several times larger than the lethal area of a typical fallout pattern.

7. In this paper, all weapon yields are assumed to have a two-thirds ratio of fission yield to nominal yield. For other ratios, multiply the fission yield by 3/2 to express the yield in our units.

8. All weapons are presumed to be delivered within a time interval not longer than necessary so that they can be considered as simultaneously delivered, i.e., so that there are no significant biological recovery effects during the total duration of the campaign. (Probably two or three days suffices.)

Representative HOLIFIELD. Now, we are going to change our order of witnesses a little.

We have just received a phone call on Dr. Libby's airplane. It is en route between New York City and Washington Airport. So we are going to move up Mr. Herman Kahn, Center of International Studies, Princeton University, who presently is on leave from the Rand Corp. Mr. Kahn is a distinguished lecturer and educator and a student of this problem. He is one of the real experts of the Rand Corp., which has done many studies for the military departments.

If I could get Mr. Kahn not to talk as fast as he usually does, maybe we can follow him.

STATEMENT OF HERMAN KAHN,[1] CENTER OF INTERNATIONAL STUDIES, PRINCETON UNIVERSITY

Mr. KAHN. I will do my best.

Representative HOSMER. I think, Mr. Chairman, that Mr. Kahn and the people who have worked with him have given this subject the closest scrutiny that it has ever been given. I think we are fortunate indeed to have him before us.

Mr. KAHN. Thank you very much.

Representative HOLIFIELD. I notice that you have been here every day. You have seen a congressional committee in action over a long period of time now. I think you have a concept now of the laborious method by which we put things on record.

Mr. KAHN. I am impressed with how fast you do it. We spent a year and a half; and you have covered about the same ground in 4 days of testimony.

Representative HOLIFIELD. You see, you folks are not as expert as the committee.

Mr. KAHN. I would like to make it clear that I am appearing here as an individual. While many of the points I make will be based on work I and my colleagues have done at the Rand Corp. in 1957 and further work done at the university, the formulation, presentation, and opinions are my own. Because of the controversial nature of some of my remarks, it is very important to make this very clear.

I recently had occasion to give three lectures on thermonuclear war in New York City. One member of this committee and several members of the staff attended these lectures. I have been asked to summarize those aspects of the lectures which would be most appropriate to the function of this committee and in light of the testimony that has been heard.

The lectures were long. They took about 7 hours to give and there were about 4 hours of discussion available to amplify the remarks I made. And, on the whole, the audience was an expert audience. The reason for emphasizing these points is that I am going to have to be very light today; some of the things I will say need many qualifications, but for the sake of continuity of discussion and for the sake of just moving along, I will not be able to make all of these qualifica-

[1] Undergraduate work at UCLA. Graduate work at California Institute of Technology. With Rand Corp. for 10 years, November 1958 to present. On leave of absence since January 1959 and now with Center of International Study, Princeton University. Was a consultant to the Gaither Committee: Scientific Advisory Board of the Air Force; Technical Advisory Board, AEC; Office of Civil Defense Mobilization.

tions. This inevitably leads to misunderstandings but given the constraints of time this cannot be helped.

Let me start by making some remarks about quantitative computations. The most important reason for being quantitative is because one may, in fact, be able to calculate what is happening. Many of the witnesses have emphasized the uncertainties of thermonuclear war but if we had raised Napoleon from the dead, and had him listen to these hearings he would have been impressed with the exact opposite notion; he would have been impressed with the relevance of quantitative calculations; impressed with the accuracy with which people predict what a nuclear war is like. One could not have applied the principles of physics, engineering and biology to an Indian war. In other words, when one drops a bomb with a certain yield and CEP one can then say: "These cities will be destroyed, these bases will be put out of commission, and so on with at least moderate reliability. In particular, one can have reasonably good lower estimates of the damage.

This is of some real interest; before World War II, for example, many of the staffs engaged in estimating the effects of bombing overestimated by large amounts. This was one of the main reasons that at the Munich Conference and earlier occasions the British and the French chose appeasement to standing firm or fighting. Incidentally, these staff calculations were more lurid than the worst imaginations of fiction.

In our case, when we say a building falls down, it very likely does. When we say a person is killed with a thousand roentgens, he very likely does die. Our calculations are more likely to be underestimates than overestimates since the effects we have overlooked are obviously not in the calculations. This means that the picture of horror that is painted of a war today is in some sense reliable. It really may happen as described.

On the other hand, one can still overestimate the horror. I would like to associate myself with the spirit of the last witness' testimony in emphasizing the importance of a nation surviving, and of looking at what survives in addition to what is destroyed. I do not like his analogy of the handicapped individual, because that gives the feeling of being crippled for the rest of one's life. One never really recovers from a handicap such as the loss of an arm. One can only adapt to the loss and live with it. This is, in fact, the picture most people have of a thermonuclear war—of a sort of permanent setback, if not a form of annihilation. I also would like to point out this is an expert picture, just as in World War II, but more so. Most of the experts, whose duty it is to plan for wars or who write about the subject, do have a picture of a war which is even more lurid, than that which has been painted in the last 4 or 5 days.

It is because of the enormous impact that the introduction of thermonuclear weapons has had on people's notions of what a war is like, that one has had the extreme, I might say almost 100 percent, dependence on the theory of deterrence. This has been coupled with an unwillingness and an inability, a psychological inability, to analyze what deterrence means. In other words, when one has to depend on something working, one cannot afford to question the underlying assumptions; it would be too disturbing, if one did, too disturbing for ourselves and for our allies, if we raised questions that shook our faith in the notions.

In my testimony today, I am going to comment not only on the testimony given to the committee, but on the expectations raised by this testimony and some of the qualifications that should be made on these expectations that might affect our actions, our allies' actions, and Soviet actions, and equally important, how the various ways in which a war could start would affect the kinds of calculations we make here today. That is, the calculations that have been presented, as has been emphasized, are a sort of average calculation, an average which, in fact, would probably never occur. If one only had to make one calculation, this is the kind one would make, it is the kind we have made in the past. It is worth noting that these calculations are very similar to those the Rand Corp. did about 2 years ago, and that they were made independently. That is, the committee drew up the attack without any reference to what the Rand Corp. had done.

So I am not trying to say that the assumptions are bad ones to use. I am saying they are bad assumptions as far as predicting what will happen in any actual case. Not only in the sense of statistical variation, but in the sense that any particular attack pattern is likely to be drastically different from the one that has been used. It will be either worse, or better. And it is very important to understand when it will be worse and when it will be better.

Representative Holifield. This has been brought out time and again. This is a study, and we are not saying it will happen this way, and it might be either larger or it might be smaller.

Mr. Kahn. The other reason for using quantitative calculations is because one may want to communicate reasonably accurately. The situation itself may not allow much precision in the analysis. One may literally not be able to predict what will happen, but still have strong feelings about what may happen, and wish to communicate these feelings. It is not very useful in such communication to use words like total destruction, annihilating retaliation, end of civilization, and so on. Such words would be appropriate if the target system were overdestroyed. If one has killed a man by an approximate factor of five, nobody really cares whether it is two or ten. Dead is dead. But as soon as one does not overkill the target system, as soon as in fact half, two-thirds, or three-quarters of the target system survive in a significant way—and I hope to explain what I mean by "in a significant way"—then one must be a little more precise in one's statements. It is true that some of the levels of destruction discussed here are unprecedented. But unprecedented is not unlimited. These are quite different remarks.

I would like now to ask the committee's indulgence to my using a debating trick which I have found very useful in the past to illustrate a very important point.

The reason I have to use a debating trick is very simple. It is difficult in a period of a short hearing, even hearings of 4 days, to get people to take these problems seriously, and to do it one has to trick them a little bit.

Let me give you a history of this debating trick, and you will see exactly what I mean.

I had occasion recently to attent a conference on NATO problems at Princeton University. We had both Europeans and Americans

present. Some of the Europeans raised the question: Would American aid be on the way if the Russians seriously challenged us? Would we live up to our alliance obligations?

Using quantitative statements—particularly if they are presented in a detached and objective manner—has another disadvantage. It sometimes gives an impression of almost incredible callousness. In some ways this may be to the good. If you want a detached and objective analysis, then you probably have to do it in a detached and objective manner. This doesn't, of course, imply that you approve of the subject being analyzed—only that you think it is important to understand it. For example if one says that it is not true that everybody is killed but only 50 million people are, this does not mean that the speaker is implying that 50 million people are a small number, but that 50 million people are much less than 150 million.

Now, one can today get up in front of any audience in the United States and make a remark to the effect that the credibility of the nuclear deterrent as a protection of Europe is diminishing close to the vanishing point and nobody will get angry with you. If you make an almost identical remark to the effect that we may not live up to our alliance obligations, people will throw you out of the room. But the two remarks are, in fact, almost identical, if you think about them a moment. The difference is not that the first is a polite way of saying something which is very awful, but that people refuse to accept the immediate consequences of the things they believe.

Most of the Americans at that conference, particularly those with official responsibilities, were horrified at the European notion. Such thoughts in fact almost do not enter any American's head today and possibly never will. And I should make it clear, I am not predicting that they will. However, it is worthwhile pointing out to Americans that the issue is a serious one, one which must be faced, considered and discussed, and if necessary preparations made. If you are afraid to discuss the issue, you will certainly be afraid to meet the crisis when and if it occurs.

Representative HOLIFIELD. This principle is one which this committee has decided was the correct principle. In other words, if we are living in this kind of world, and if these weapons actually exist in the quantities in which we know them to exist, if the deliverability is what our experts on both sides of the fence say it is, then it is time to face these problems and start discussing them, as you have just said. Start trying to find, or maybe accelerating our effort to find, some solution.

Representative DURHAM. How does that enter into the picture? How would you calculate in figures, so that you would put it into the actual picture of a calculated attack, whether or not we would live up to our obligations when and if war were declared?

Mr. KAHN. That is exactly the question I want to address myself to.

To what extent will these calculations affect policy? And I want to ask this question from three points of view. From the Russian point of view: Would they believe we would live up to these obligations? From the European point of view: Would they believe it from the calculations they would make? From the American point of view: Do we believe we will do it and would we, in fact, do it?

You understand, any two of these questions can be answered yes and the third no, and one still has an unpleasant situation. All three must

be convinced of the right answer, and let me repeat, one does not convince the Europeans or the Russians by being afraid to discuss the matter. Just the opposite. One shakes confidence; if we cannot face even a verbal discussion, we certainly cannot face the real thing.

Even though I believe this, I would not be in favor of raising this question in a public and official record if I did not feel we could do things about the inadequacies of our posture in sufficient time for them to be corrected. In other words, if we had passed a point of no return, I would prefer closing my eyes and just sailing ahead. I do not believe we have passed that point, and that is why I think it is important to discuss the problem.

I am trying to demonstrate that things for which normally there is no price, one can sometimes set a price which one knows is big enough, and another which is not. In other words, one can establish a principle, and after the principle is established, one can then haggle over the price and try to reduce the range of uncertainty.

Representative DURHAM. You mean the price of lives?

Mr. KAHN. In this case we are pricing both lives and honor. Now let me establish the principle, if I can, sir.

Let us assume that the Russians had such a competent retaliatory force, and that our own defense, both active and passive, were so weak, that even if we struck the Russians first, in their retaliatory blow they could kill every single American, all 177 million of us. Now, we know this is not a condition which in fact obtains. They cannot do it. But let us just assume it for the moment. Now let me ask every man in this room to put himself in the place of the President of the United States. Assume that the Russians have done something very horrible, say dropped a bomb on London, on Rome, Paris, Berlin, the worst thing you can imagine, but have not touched the United States. By some mechanism (I will describe some possibilities later if I have the time) the President cannot react immediately. He has 24 hours to think over what he will do; at which point he has to decide whether to press the button and punish the Russians, but in turn accept the extinction of the United States of America. And I mean complete extinction.

Now, if you have 24 hours to think about it, you are not going to think about it in isolation. You are going to call a meeting and talk about it.

I do not know how the President would act, and I do not know how I would act under those circumstances. But I do know that one could not blame the Europeans or the Russians for believing that we would not retaliate. Under the assumptions one just cannot blame them for so believing. And, in fact, it is very doubtful that we would retaliate.

Now, if you believe this, then you have to ask: If that principle is possible, what is the price? Let us now haggle over the price. It is clear that we cannot establish an exact exchange rate between lives and honor, between current and future evils. We cannot say whether the Soviet retaliatory threat would be effective at exactly 5 or 30 or 100 million dead. That cannot be done. But I have discussed this question with a number of Europeans and a number of Americans, and they do have feelings about the subject, and they can communicate their feelings. And I might say their feelings change. That is, in

the first few minutes, if you just ask a man to react, many Europeans will say, "At no price will the Americans retaliate." He thinks it is just a bluff. Many Europeans do. On the other hand, the typical American will say, "We cannot be bluffed or blackmailed at any price."

But if you think about it for a few moments, just 5 or 10, not 5 or 10 days, but 5 or 10 minutes, it soon turns out that your price, if you are an American, tends to be in the 10 to 60 million range. And you get 60 million by a very interesting process.

Representative DURHAM. Do you know any time of history when the Americans were attacked that they have not retaliated?

Mr. KAHN. I know of no such occasion. And I do not believe we would not retaliate today. Not only if they attacked America, but if they attacked Europe. I think we will retaliate. I am not trying to cast doubt on the fact that we might retaliate today. However, I am doubtful that we might retaliate 2 or 5 or maybe 10 years from now, if and when the counterthreat gets worse and we do nothing to meet it. I will cast doubt on that.

Representative HOLIFIELD. Under what two conditions did you say?

Mr. KAHN. I would say that today the threat of a Russian counterattack is not large enough to prevent us from living up to our obligations; I believe that this may not be the case in a relatively short number of years, though I am not willing to say whether this is 2 or 10, but well within the lifespan, prospective lifespan, of every man in this room.

Representative DURHAM. You do believe, Mr. Kahn, that we will live up to our obligations, do you not?

Mr. KAHN. I say we will live up to our obligations in the near future, as of today. I am not at all certain—in fact I rather think the opposite—as to living up to our obligations from 2 to 10 years from now, depending on technological progress, the military and nonmilitary defense programs we have, and the progress the Russians make.

Representative HOLIFIELD. In other words, you are anticipating technological increases which will make complete annihilation of both countries a matter of certainty as far as capability is concerned?

Mr. KAHN. Not complete annihilation. Just a third or a half the country is enough. In fact the attack that has been discussed in this room may be enough. But the attack that has been discussed in this room in the last 4 days is an unrealistic attack for these circumstances. And I will explain later why this is so.

Let me for a moment discuss the opinions of the Americans and the Europeans that I have polled.

The way one gets 60 million casualties as a price one cannot afford to pay is by taking roughly one-third of the population. In other words, I have yet to meet an American who, after he thought about the problem 10 minutes, was willing to sign his name to a statement that he believed the United States would go to war deliberately, in cold blood, on any issue short of a direct attack on the United States, if more than half the people in the United States were killed on the Soviet retaliatory blow. It has to be less than half. Some Americans, as I say, argue that we would be blackmailed into acquiescence if we were threatened with only 10 or 20 million casualties. Those few Europeans I have talked to have a much weaker impression of

American tenacity, American purpose. Their estimates lie between 2 and 20 million. And it is important, you understand, that they have a proper opinion, too. I have no feeling at all what a Russian estimate would run. Absolutely none. I do know it might run very high. The Russians lost something like 10 percent of their population, and, they claim, about one-third of their wealth, in World War II. And they know they recovered from that. While they are still appalled at the damage they suffered, they can think in these large terms. So the Russians might be very impressed with the U.S. capability, and the United States might in fact have both the will and the capability, at a time when the Europeans did not believe it. This is a very possible situation, and in some circumstances, a disastrous situation.

It is important, in other words, to differentiate very sharply between what I have called Type One Deterrence, which is trying to deter a direct attack on the United States, and what I have called Type Two Deterrence, which is trying to deter an extremely provocative action. In the first case, many things enter Russian calculations as to whether they should attack the United States or not. But one of the most important things which will enter their calculations is their estimate of what would happen to Russia if they struck the United States at a time of their choosing and we strike back, with a damaged force, in the teeth of an alerted air defense, and in some instances after the Russians have evacuated their cities.

Type Two Deterrence, deterring extremely provocative actions, involves a quite different calculation. It is again a Russian calculation. Only now the Russian asks himself: If I do this very provocative thing, which is less than a direct attack on the United States, but which is still very provocative, will the Americans start the all-out war? That must be influenced by whether or not the Americans think they can survive our counterattack. And that means the Americans must calculate that they strike first and we Russians strike back with a damage force. Things will be completely reversed from the Type One Deterrence calculations.

I might point out that in both World War I and World War II it was Type Two Deterrence we were talking about. That is, the British declared war on the Germans, and not vice versa.

Representative DURHAM. In those conditions you would not think we would strike back? Is that true, Mr. Kahn?

Mr. KAHN. No, I believe, and I should make this very clear, that if the Russians did something very provocative in Europe today, we would live up to our alliance obligations and strike.

Representative DURHAM. I was thinking about the 6, 8, or 10 years you were talking about.

Mr. KAHN. I believe that under current programs we will not.

Representative HOLIFIELD. Now please define the current programs.

Mr. KAHN. We have certain programs in the field of air and missile offense and air and missile defense, and civil defense. Add them all up, and it is hard to believe that we would be willing, and I do not wish to be specific in years, because this would get us into the classified field, but at some time in the future we will in fact be outbid, under current programs.

Representative HOSMER. That would include the consideration of whatever measures we take over and above what we have at the present time to reduce the effect in our own country of the attack?

Mr. KAHN. That is correct. There are many things to be done in both the civil and military field. I would prefer not getting into that at this time.

Representative HOSMER. You say in plus X years our decision might be different, yet that decision not to engage might never be presented to us, because we would be in condition sufficiently to ameliorate our damages.

Representative DURHAM. On your theory, Mr. Kahn, then we would not have any war? Is that your idea? That things will get so terrible in the future that even Russia would not take a chance on attacking some other nation?

Mr. KAHN. There are two separate questions. One, involves such things as, for example, a Russian attack on West Germany. In this case they have not started world war III. They have just started a small war. At that point it is up to us to decide whether to start world war III, not the Russians. I am just giving you a hypothetical example. In other words, we must not confuse the horror of world war III with that which is risked when the Soviets try a moderately violent action. That is a quite different thing.

Second, the situation may not be symmetrical. It is conceivable that there are circumstances in which the Russians could strike the United States and accept our retaliatory blow, when we would not be willing to strike them and accept their retaliatory blow. This has to do partly with the intrinsic vulnerabilities of the two countries. As you know, we are a much more concentrated country than the Russians. But mainly it has to do with their attitude toward war and the seriousness with which they pursue preparations. The Russians, for example, have a very large civil defense program. It happens, as far as we can tell, to have some inadequacies. The intellectual basis of the program is very bad. It was not until 1954 that Soviet civil defense authorities discussed 20 KT bombs, it was not until the last year or two that they dropped the 20 KT bomb for the 20 MT bomb. We have been 3 or 4 years behind the problem. They have been 7 or 8. But if you look at Russian manuals, you will notice an enormous increase in understanding, ability, and capability in the last few years. I do not wish at this time to get into Russian programs. Mr. Holifield's other committee in the House has put out a report on Russian civil defense which has most of the information in it. What I am saying is that the Russians in 1954 and 1955 had a great debate on the theory of the "minimum deterrent." Malenkov said, the next war would mean the annihilation of civilization, "And therefore we lucky Russians don't have to have such a large force as we used to have, because if it really is annihilation, nobody will start a war, and we can afford to get away with a much cheaper strategic force. We can start concentrating on consumer goods."

He was forced to retract publicly on that argument. Khrushchev argued that wars weren't that bad and that the Soviets had to be prepared to fight and win wars in addition to being able to deter them. This was one of the major debates that they seem to have had and Khrushchev seems to be the official winner. As a result the Soviets have gone for a capability to win wars rather than to deter wars.

This is a deliberate choice on their part which involves them in great expense.

Whether they have carried through completely on that decision is not known in this country, in other words, one often makes a decision and then does not carry through. There is some evidence to the contrary, evidence that they have expanded the civilian sector of their economy at the expense of the military economy. But insofar as we can tell, they did make a decision in 1955 and 1956 to buy a capability to fight and win wars and have done some of the things they need to do to implement that decision.

We are making the exactly opposite decision. We are making a decision to deter wars. Failing deterrence, we do not talk seriously about the consequences.

And as I said earlier in the day, we do not analyze carefully what we mean by deterrence, because we have staked too much on the notion working to be able to analyze it objectively. There is too much that we are risking to be able to discuss the subject calmly, quietly, and objectively. Many of us feel we cannot afford to weaken our resolve by even thinking about possible weaknesses.

I think, though, that it is important that we do think this problem through, and this is why I was delighted at these hearings being held.

Representative DURHAM. You have to think pretty seriously to spend $70 billion of the taxpayers' money which goes directly into the defense and security of the free people of the world.

Mr. KAHN. Let me give you an example of what I mean. There is a great deal of criticism of the Federal Government today, to the effect that they are not spending enough money on defense. Nevertheless, there was a recent decision to cut back on air defense. As far as I know, that decision was not criticized publicly by anybody. The only criticism which was made of that decision was that the cutback on defense against bombers did not go far enough. Yet some years ago, in 1956, when General Partridge testified on the state of our defenses, he made it very clear they were not adequate to defend our country and would not be adequate in the near future; his testimony did not depend in any sharp way on large estimates of the numbers of Russian long-range bombers; their TU–4's, and Badgers, and small numbers of Bears and Bisons, being sufficient. They did not have to have 500 or 1,000 Bears and Bisons to do the job.

The reason why there is no criticism of the decision to cut back on air defense is that people believe we must deter allout war, we must be able to fight limited wars, we must have arms control and that is all. They do not really believe we have to be able to fight a general war, usually not because they are certain one cannot happen, but because they do not believe that anyone can survive a general war. They do not believe that there is a significant difference between victory, stalemate, and defeat.

The testimony before this committee was I think in that sense very salutary. As far as I know, Frank Shelton was the first Government official to make the flat statement that the next war would not destroy all human beings, worldwide.

This may strike those who know, in this committee room, as a rather silly view, held by maybe a few uneducated laymen. It is not like that. Very distinguished scientists hold that view. And I mean very

distinguished. And a couple of years ago they would have been willing to argue with you numerically that they were right. In fact, in the 1957 fallout hearings before this same committee, when questions were asked of the various scientists—unfortunately I do not have the exact quotations with me—but such questions as "What would happen if the Soviets dropped 100 5-megaton bombs on the United States?", the answer was generally to the effect, "I haven't made that calculation, but we couldn't take it." There was a recent debate in the New Leader magazine between Bertrand Russell and Sidney Hook on "Was it legitimate, or was it not, to risk killing all human beings in the world in the attempt to resist communism?" That was a serious debate. Nobody raised the question, that the debate was about a hypothetical subject which was not at issue. One does not kill all human beings, or even a majority of them, in a war. Today, in England, in France, serious experts on war almost always discuss the issue of war or peace in terms of world annihilation; never in terms of "the damage is great." In terms of, "Is the damage too large to accept, or will we prefer accepting that damage rather than appeasing or surrendering?" That is never the question. The question is always debated in terms of world annihilation or no world annihilation. This in spite of the fact that there is no scientific backing for that view for any practical kinds of wars that may occur in the near future.

Senator ANDERSON. When you say there was no objection to the cut back in the Air Force, are you really sure about that? Did not Senator Symington have quite a bit to say about it, and did not others in the Senate?

Mr. KAHN. I believe they had a lot to say, but always in the direction of wanting to cut back on air defense more. I would like to check it, but I believe that is correct. The statement was, "You people are still in the horse and buggy era. You are fighting ICBM's with chariots." The argument was always that we should shift more to defense against missiles, shift more to our deterrent force, shift more to limited war forces. As far as I know, and I am reasonably well read, though I did not expect this subject to be brought out today, so I did not check on it, there was no public voice raised in any of the standard large newspapers—I was curious, so I looked at all the editorials I could find—or any statement issued by any Member of Congress, that the cutback in active air defense was too much. The argument was all on the other side, that the cutback was not enough, in the defense against manned bombers. I am almost certain I would remember if I am wrong.

Representative HOLIFIELD. You confine that to the defense against manned bombers?

Mr. KAHN. Defense against manned bombers, that is, Nike, Bomarc, interceptors. I am not here making any comments as to Nike versus Bomarc or anythink like that. I am simply discussing the conceptual idea that people think the notion of defending against manned bombers is obsolete. This is a view that is widely spread, widely held in many places. Most people hold this notion as much because they think defense is obsolete as because they think bombers are obsolete.

I hope later to get into the philosophy of the deterrent forces, and this is very much connected with this notion.

I should make one other small point before I go into the systematic discussion, even though we are running out of time. And this is the question of the symmetrical character of what I call Type 1 Deterrence. In order to make it easier to remember, let me use the same terminology the British used. The British refer to the type 1 deterrent as a Passive Deterrent, because they argue it takes no act of will. In other words, if he strikes you, you will strike back. It does not take any courage or any will. They refer to Type 2 Deterrence as an active deterrence, because it takes an act of will. You have got to be willing to strike the enemy when he provokes you by striking a third party. It is not automatic.

Let us now consider Russian Active Deterrence for a moment, and ask ourselves: Is it easy to deter the Russians? Can we afford to provoke them as far as we wish to go?

Let me give an example. In 1956, there was a revolution in Hungary which the Russians suppressed. There was at that time much pressure on the United States to intervene in that revolution to support the Hungarians. I myself felt rather strongly we should do something. However, I wish to ask the following question: If we had intervened, would the Russians have accepted that intervention, say in 1956? Would they accept it in 1960? These are different situations. It is possible that we did more than not intervene. There are rumors—I do not know if they are true or not—that we broadcast to the East Germans and the Poles not to rock the boat, that American aid was not on the way if they did. There are reasons for worrying about a satellite revolt spreading and, if we had intervened, it is quite clear that there would very likely have been a widespread satellite revolt. Particularly if the Russians did nothing, if they just let us get away with it. After all, some of the satellites revolted without any American intervention.

A satellite revolt is a very big thing to the Russians, and they might not be willing to stand for it. Much more important, the Russians are greatly concerned with internal stability. Most Russian experts that I know of think of the Russians as having a very stable government, unlikely to be upset even by really quite catastrophic events. But it also seems to be true that the Russians do not think of themselves as quite that stable. They worry about internal revolution in Russia more than we do. And they might think of a successful satellite revolt as an intolerable event that might lead to the end of the regime.

They would, I think, be under pressure to fight if we intervened in Hungary. If the fight was on a high explosive basis, I think we would lose. If the fight was on an atomic basis, I think we would probably still lose, but now there would also be side effects. If the fighting were limited to Hungary, there would probably be widespread destruction within Hungary because neither of us would wish to lose without making a major effort. If we tried to limit the damage by attacking supply lines in rear areas we would be getting into Russian territory. Now, the Russians might think at this point that at any moment the war could erupt either into a satellite revolt or into a large scale attack on Russia. They might be particularly will-

ing to worry about the latter because they would find it very hard to believe that we intervened with the expectation of losing. In any case, it is a very large war being fought near Russia. They might then ask themselves the following question: Rather than wait for this war to erupt into a satellite revolt or into an American surprise attack on our strategic force, maybe it is safer for us to hit the United States and thus at least assure our getting that all important first strike—at least if we hurry.

In other words, they might argue that going to war is very risky, but possible less risky than not going to war. At this point we must ask the question: How risky is it for the Russians to go to war?

Well, in late 1956, it was very risky for them. We had a very large strategic force and one which was very alert. Even if they attacked the United States and caused much larger levels of damage than that discussed here, our strategic force would have flown away before they could have damaged it.

This situation may not, however, be as true in the future, for a number of reasons.

I would like to make this one observation at this point. If the Russians can limit our attack on them to about the size of this attack on the United States, then if they have made very modest preparations, they do not suffer a great deal of damage.

What do I mean by this? I mean that if they can evacuate their civilians to places of safety, radiological safety; then we can't kill very many Russians. There are lots of places to evacuate to in the Soviet Union. Let me give some orienting numbers. There are less than 50 million people in the largest 135 Russian cities. As far as we can tell it is perfectly possible to evacute 80 percent of this urban population and have all vital functions in the cities performed. This would leave only 10 million people at risk in 135 cities. Having been alerted, these could evacuate on very short notice. In addition it is very difficult to destroy 135 Soviet cities in a retaliatory blow. I am not saying we could not have done it. I think we could have, in 1956. But it is a difficult thing to do. You can see it is difficult. In any case it is a larger attack than this one.

Even if it did not kill many people such an attack would cause a lot of economic damage in Russia. But the Russians claim to have lost one-third of their wealth in World War II, and they recovered from it. In fact they recovered by 1951. And they know they recovered from such levels of damage, because they mention it. In other words, the Russians know that it can pay to accept very large amounts of damage, rather than to surrender, because they have actually gone through the experience. And while that is a very hard way to learn, it is also a very convincing way to learn by having actual experience. This doesn't mean they would be glad to repeat the experience—only that they may be willing to under less pressure than we would be willing to.

I mention both of these cases, because I want to put the rest of my discussion in context.

One not only has to ask himself what it costs us to go to war under certain circumstances, how do we feel about it, how do the Russians feel about it, how do the Europeans feel about it, but also the same set of questions about the other possibility—about Soviet willingness

to go to war. All of these questions must be asked. As I said, it does no good to convince the Russians and the Americans if you do not convince the Europeans simulaneously. Otherwise, we may get into real problems.

Representative DURHAM. Mr. Kahn, do you think that has anything to do with a man's will to fight for what he believes in?

Mr. KAHN. I believe it is very possible for a soldier to die for a squad, a squad for a regiment, a regiment for a division, a division for an army, an army for a nation. I doubt that under most circumstances it is possible for a Nation such as the United States to die for the world. It may be all right to fight to the last man, but most civilized nations will surrender or at least negotiate before fighting to the last woman and child.

Representative DURHAM. I am talking about the fact, of course, of the recovery in Russia. And of course they know what it will cost them.

Mr. KAHN. What I am saying is that I think both the United States and Russia will fight if sufficiently challenged, so long as there is at least a moderately good chance of their nation surviving the war; that if there is no chance at all of the nation surviving the war, they will not fight if only challenged. They will then only fight when they are in fact hit, rather than challenged. This remark is only reinforced if you believe the stakes are world annihilation.

What it amounts to is that you have to believe in life on other planets, in order to fight. And the evidence for that is scarce.

Now, actually, discussing this problem just in terms of casualties is very misleading, because if you ask: Why is it that most of the experts do not believe in recovery? It is not because they are worried about the large number of immediate deaths. It is because they are worried about the medical, economic and social problems of the postwar period and the long-range genetic problems. I have listed here the eight phases of a war one has to look at if one is trying to analyze. I would like to discuss these backwards, because that is the order of importance. (The list is in the outline of lecture I in the prepared statement, p. 921.)

Let me therefore start with the genetic effects as discussed at this hearing and as studied by our own people.

The first thing one has to decide is: What are the standards by which one is to measure if the situation is tolerable or intolerable? Now, there are three kinds of standards one should look at. First there are the prewar standards, the standards by which we regulate our public health today. There are the standards to be used during the war and immediate postwar situation. What will you accept when things are actually happening? You will for example accept 5 million casualties going without treatment and thereby dying, because there is no alterative: there is no way to treat them. You will simply add these casualties to the total of the fatalities. Then there are the postwar standards. Now, this war is a horrible thing, and its horror lasts for some thousands, actually tens of thousands, of years. The environment is permanently more hostile after such a war, in the sense that anything over 1,000 years is permanent, as far as we are concerned. And it actually turns out that if you believe that in the postwar world you will not live in an area which is unsafe to live in by

current peacetime standards, then you would abandon much of the country for decades. You will walk away from it. As you might guess, it probably won't be like that. We will both put in alleviating measures and adjust our standards. And the question that one has to ask oneself is not, "Will we abandon the country?" since there is no place to go, really, but how bad is it for us to use these alleviating measures and to readjust to reasonable postwar standards? Can I as an individual on the average hope to live a happy life? Can my descendants? Can society function in a way which we like to think of western societies functioning? Or will we live as the savages live, as some of the Asiatic nations live, with life expectancies of 25 years? When one asks the question this way, one may find situations "acceptable" in which the overall damage is really fantastically high.

Let me now make a comment or two about the genetic damage. We had testimony earlier that there might be a billion individuals injured if the survival was only 40 million. It was estimated that between 1 and 4 percent of this toll is represented by live, seriously defective individuals. No man can deny that this particular legacy of a war represents human tragedies in the most extreme form. However, the rest of the defects, representing 96–99 percent of the total, have a much smaller impact. Something like a half to three-quarters were so-called prenatal death, or early miscarriages, or things of that sort.

Now, while that may be an individual tragedy, it is not a social tragedy. In other words, Americans have so much excess fecundity that even if there are many early miscarriages, it does not affect society, though the individuals affected may be seriously perturbed.

It should be pointed out that many of these early miscarriages are not even noticed by the woman who is involved, because they occur very early.

The rest of these genetic defects were described as minor defects which might affect the health, happiness, and vigor of the individual but which generally do not show up in a dramatic way. It is very hard to estimate the impact of such minor defects. In particular, I think that here the geneticists tend to be somewhat misleading in their estimates of the impact, because they do not think or talk like economists. For example, there is a theorem in genetics which says something like the following: That almost any defective mutation is just as bad as any other mutation, because almost every defective mutation eventually causes a death.

In fact, sometimes a geneticist says that insofar as two mutations do not cause exactly the same damage, the one that results in a minor defect may cause more damage. The reasoning goes as follows:

The minor defect is carried along generation after generation, affecting the health and happiness of each of its bearers adversely, until finally it tips the scale against an individual, causing him to die, terminating that genetic line. So both the minor and the major mutation killed an individual, but the minor not only killed an individual but affected the health and happiness of many other individuals in the process. And one acn therefore argue that the minor mutation caused more damage.

The theorem is misleading, yet it affects a great deal of thinking among geneticists. It is misleading because, among other things, it

ignores a fact that any economist is familiar with, that one has to discount the future.

Let me give an example why this is proper if we are to use the words harm, damage, et cetera, properly. If I were asked to choose between three situations—a situation in which 100 percent of the people were killed immediately, or a situation in which 10 percent of each generation died prematurely, for 10 generations, or finally a situation in which 1 percent of each generation died prematurely for 100 generations—then the total number of individuals killed is exactly the same. But I think there is no question which situation most people would prefer.

In other words, if you can spread the damage over tens of thousands of years, you have done something very useful, and if the spread occurs naturally one must take account of the distribution of damage over time when one asks: How does it affect society or the average member of a society? One cannot just add up arithmetically over tens of thousands of years, the total amount of damage if one wishes to answer this question. From some moral points of view, the simple arithmetic sum may be the right way to think, but I have doubts even about that. It is true that "a human being is a human being." But, moral questions aside, from the viewpoint of how we as individuals view our personal expectations of happiness or our society's ability to function, the simple arithmetic sum is almost irrelevant.

I am not, in other words, discussing the moral question: Is it worse to kill a man 10,000 years from now or to kill him today?—not because I am not interested in that question, but because it is irrelevant to what I am discussing right now. That kind of question typically will not affect calculations of deterrence. It just does not.

I would like to tell a story to illustrate how strongly people feel about genetic damage, sometimes unreasonably strongly. At one point, I was induced, against my will—and I was sorry both before and afterward—to give a talk at UCLA to a mixed audience, on what a war might be like. I mentioned that in a typical war if one had taken modest preparations the survivors might get about 250 roentgens, that this dose might mean that for the next generation and some generations to follow 1 percent of the children would be born with serious defects, who would not otherwise have been defective, such defects as idiocy, blindness, crippling, and so on.

Then I added, injudiciously, that "One might be willing to accept that cost of a war, rather than give up Europe to the Soviets," or that under certain circumstances the Russians might be willing to accept that cost of a war in order to eliminate us. A woman got up in the audience and said, "I don't want to live in your world where 1 percent of the children are born defective." She then made some other rather pointed remarks.

I was outraged and answered, "It isn't my world." I have nothing special to do with it, I have to accept the same responsibility as everybody else in this room, but no more. I then pointed to my chart, which said: "About 4 percent of the children are currently born defective." Then a friend of mine offered the lady a knife. He was pretty mad, too.

The point of this story is that peace also has its tragedies. I can easily imagine that if we had lived in a world in which no children were born defective and we were told that as a result of some action of the Government or of a war that 4 percent of the children would be born seriously defective we would consider such a world to be intolerable. We just wouldn't be able to believe that people would be willing to bear and raise children if the risk were about 1 in 25 of these children having a serious congenital defect. However, we live in that world now and we not only bear this relatively high rate of tragedy, we almost ignore it. While some women have a great concern about such possibilities during their pregnancy it is only in such critical periods or when there is a tragedy in the immediate family that most people think about this burden of life. To add an additional 1 percent to the burden would be a terrible thing to do, but it is clear that this additional burden is comparable to the kinds of risks with which we have become accustomed to in the peacetime world, and that most people will be able to live with such increased risks.

In other words, war is horrible. There is no qustion about it. But so is peace. To some extent the horrors of war are only an increase or intensification of some of the familiar horrors of peace and if you present a government with a sufficiently unpleasant peacetime situation it may decide that it prefers to go to war and accept the postwar world to living or temporizing with the peacetime problem.

This is one reason why it is useful to make the kinds of calculations we are making today, to compare the horror of war and the horror of peace and see how much worse war is. This is an emotion-laden issue, partly because it gets mixed up with the question of nuclear testing where many people have overdone such comparisons or said, rather violently, that they are totally irrelevant.

It is perfectly possible, by the way, to feel that the nuclear tests cause too much damage but that the war does not, in the sense that the tests should be judged by peacetime standards and the war by wartime standards. These are not logically inconsistent views to have.

In any case, as nearly as I can see, if you have a reasonable economic recuperation, the genetic effects resulting from one war cannot jeopardize overall standards of living. It is difficult, if not impossible, to give people much more than a thousand roentgens in a war without killing them. Only the survivors have children. If current beliefs are true, 1,000 roentgens should at most double the normal burden of defects, probably less.

Now, doubling the number of burdens of defects is an enormous thing to do, but it should be almost clear that the medical and social cost to society of the current burden is not so high that we could not accept a double burden without jeopardizing the functioning of either our system or the Russian system. The individuals who are directly affected, of course, would feel involved in a tragedy. The rest of us would get along.

I would like now to look at the long-term medical effects of the war, again in the same context. Can we depend upon such effects as providing an automatic and reliable deterrent? As always, I want to ask the question both ways.

One problem which has raised much concern is the strontium 90 problem. It is possible to make a technically respectable calculation

which states that every time the Russians test a large bomb in the Soviet Arctic or we test one in the Pacific something like 1,000 to 10,000 individuals now alive will get bone cancer or leukemia as a result of that test. Nobody really knows, but you could put out such a calculation and not be read out of the profession. You can print it in a professional journal. It is a respectable calculation.

I think it is rather high, myself, but I would not care to challenge it as being obviously wrong.

Many people have argued, both in the technical literature and in the literature of war, that if so few bombs so far away cause so much damage, would not a lot of bombs, very close, be annihilating?

Many "experts" have written that the backlash effect of fallout is itself a sufficient deterrent; in other words, that if the Russians drop a lot of bombs on the United States, they would be wiped out by the worldwide fallout. The simplest kind of arithmetic indicates this is not correct. In this attack you drop 4,000 megatons, which produces, say, about 250 times as much worldwide fallout as testing a large bomb produces. If one takes the largest number, 10,000 leukemias and bone cancers as resulting from testing a large bomb, and multiplies that by 250, one gets 2,500,000 individuals affected by worldwide fallout. The Russians have less than 10 per cent of the population of the world, so if they received their prorata share of the backlash they would have to suffer 250,000 premature deaths over the next 30 or 40 years. That would not deter them from any action they badly wanted to take.

Furthermore, as I said, these numbers are probably overestimates. The backlash is not even an unreliable deterrent.

In fact, we have had a lot of testimony in this last 4 days, to the other effect, testimony which is new in the sense that it is rare for anybody to publicly take a sober view of this unpleasant subject.

Representative DURHAM. Mr. Kahn, do you think that kind of reasoning has anything to do with the fact that of course they will not agree to any kind of a testing ban at Geneva, which has been going on since last October?

Mr. KAHN. No, I think the test ban has the problem that the Russians do not want a system which could be used to give us intelligence and we do not want a system which is so loose the Russians could cheat, and those two desires meet head on. I think we are both willing to have bans if we can compromise these other desires.

Representative DURHAM. You know, of course, that they are putting strontium 90 into the air every time they run those tests.

Mr. KAHN. There are many reasons for stopping tests.

Representative DURHAM. I was just basing it on what you assume they could take.

Mr. KAHN. The biological effects of testing are not an overwhelming reason, as governmental decisions go, for stopping tests. The tests very likely do a lot of damage. But almost anything you do in society causes damage. If you were willing to stop tests for this reason alone, you would stop a lot of other things.

For example, there used to be a rule that every time you built a million dollars worth of construction you killed somebody.

Representative DURHAM. I assume you are saying that we can take the 2.5 million casualties and continue the testing, put the strontium in the air, and take those results.

Mr. KAHN. I am not predicting 2.5 million casualties as a result of testing.

Representative DURHAM. If you keep on testing, we will have as much in the air as we have in a war.

Mr. KAHN. With vigorous test programs you could get quite a bit.

Representative DURHAM. Do you want to put it out all at one time, or in the next 50 years, in other words?

Mr. KAHN. I believe if the issue came to having a defense or not having a defense, both sides would be willing to continue testing and accept the biological damage. I do not think that is necessarily the right issue, but if that were the issue, both sides would continue testing.

Mr. Chairman, I did get a little elaborate in my introduction. I am not sure how much more time I should take.

Representative HOLIFIELD. What is the pleasure of the committee?

Senator ANDERSON. He is doing fine.

Go ahead.

Mr. KAHN. Let us look at the strontium 90 in a bit more detail.

Representative HOLIFIELD. Speak a little slower, please, and a little plainer.

Mr. KAHN. It is believed today that about 10 millicuries of strontium 90 per square mile would result in people living in that environment having about one sunshine unit in their body. If there is no fractionation, this corresponds roughly to one ten-thousandth of a KT of fission products per square mile. Since we allow people to have no more than 100 sunshine units in their body, this would imply that the soil is unusable if it is contaminated by as little as one one-hundredth of a KT per square mile.

Some of you may have seen statements recently that after a large thermonuclear war there would be no agriculture in the United States for 40 years; the soil would be so badly contaminated one could not eat the food. This has come up several times in questioning by various congressional committees. If you feel, as our peacetime standards indicate you should feel, that you would not eat food grown in soil contaminated by one one-hundredth of a KT of fission products, then it is very easy to contaminate the whole United States. You grow food in about a million square miles in the United States so it takes only 10 megatons of fission products to contaminate the United States to the point where you would not be willing to eat food grown on that soil.

Senator ANDERSON. How many?

Mr. KAHN. About 10 megatons of fission products spread uniformly over a million square miles of the United States. It would contaminate the United States to the point where one would not today accept food grown on that soil as fit for human consumption.

If we increase the contamination by a factor of 10, to take account of decay and weathering over the next 50 years, and by another factor of 10 to take account of overlap, one gets that about 1,000 megatons are needed to contaminate U.S. agricultural lands.

Representative HOLIFIELD. Of course, you are considering a mathematical even spread. You are not saying a 10-megaton bomb would do this.

Mr. KAHN. No. But I am saying that it is 10 megatons if uniformly spread. Multiply by 10 to take account of decay and weathering. Multiply by another 10 to take care of nonuniformities.

Now, the calculation is misleading. But it is persuasive. And you have to know why it is misleading. Otherwise, you will be persuaded.

It is wrong for many reasons, one of the most important being that the peacetime standards are probably not legitimate for the postwar world. It is also wrong because it does not take account of the fact that we will do many things to alleviate the problem.

I am not a medical doctor, and it would not be appropriate for me to suggest possible postwar standards. But just for the purpose of discussion, let me do exactly that, to give a feeling for some of the considerations which might come up.

I suggest that we would be willing to accept something like 50 to 100 sunshine units in our children, in the postwar world, not because we are happy about the idea but because it is a little difficult to achieve much less than that unless we make some preparations.

Representative HOLIFIELD. We have been using the term "strontium unit" rather than "sunshine." Some of us are allergic to this term "sunshine." We prefer the term "strontium."

Mr. KAHN. I could not agree with you more. Strontium 90 is manufactured by men. Sunshine is not. Let us keep it to a manmade object.

Senator ANDERSON. I think that term sunshine came because the first time they said if the fallout came down very, very slowly, that was good for you. And then later they said if it came down very fast, that was good for you. We decided to take the sunshine, in view of everything.

Mr. KAHN. I prefer not getting into that debate. I deal in a number of controversial subjects, but I try to keep the number down.

To continue, one might be willing to accept 50 or maybe a hundred, even, strontium units in our children, if we had to. Let us call food that would result in this or lower levels an A food. The A food would be restricted to children and pregnant mothers. One might then also have a B food which might be about 10 times as contaminated as the A food. This would be a high-priced food, available to everybody. There might then be another grade of food, a C food, which would have another factor of 10 more contamination. This would be a cheap food available to all. We are now talking about having up to 10 microcuries in new bone, which is quite a bit.

But I might point out, no one has ever seeen a bone cancer directly attributable to radioactive material in the bone at less than the equivalent of 20 to 30 microcuries. Now, we are reasonably sure that smaller amounts will cause bone cancers in a statistical sense; but I would guess that at least an adult insurance company would not raise its premium very much if one lived on food with that amount of strontium 90 in it. Ten microcuries of Sr^{90} per kg. of calcium would mean a dose of about 20 roentgens a year in the bones. This would probably cause less than a year's loss of life expectancy. The C food is especially acceptable if it is mainly restricted to adults who would pick up much less Sr^{90} than children would.

Then I would suggest another factor of 10 for a D-food, which is not available to the general public but is restricted to people over 40, or maybe over 50. It is difficult to kill a man over 40 or 50 with Sr^{90}. People of this age group do not absorb very much, and it takes 20 or 30 years to get bone cancer. One dies of something else before he does of bone cancer.

One reason why I am suggesting setting up tentative standards now is that we really have to have, before the war, some notion of what we are willing to live with, to guide research, to guide planning, and to eliminate hysteria in a crisis.

There is another reason why it is important to set up in peace the war and postwar standards we think we may have to adopt. In addition to determining these standards, the Government should formally publish them in a permanent looking form that will be available for at least postattack or postcrisis distribution. It is not really necessary to distribute all of the handbooks prewar as people can usually read them either during or after the crisis or attack, though they should be made available to all who are interested. It is, however, important to print them ahead of time, not only so that they will be immediately available, but also so that people will trust the information in them. In any such crisis many will be cynical of the integrity of the Government and will argue that the Government says these standards are acceptable because it must say so, that conditions are such that it has no choice, but that in fact the standards will result in a drastic level of casualties. The knowledge that the standards were set up in peacetime after due care and debate should be reassuring.

I am not suggesting we should publicize the existence and character of the postwar standards. I am not suggesting we should tell everybody they will get bone cancer. I am merely suggesting that the manuals be printed, stockpiled, and a small circulation made to those who are interested.

I had a discussion with a rather senior official in the AEC suggesting this. He looked at me rather amazed. They aren't very happy at the thought of putting out anything that could be construed as suggesting they are underestimating the Sr^{90} problem.

Incidentally, this official asked me, "What do you think the difference in price would be between the B and C foods?"

I said, "About 5 or 10 cents a quart."

He said, "You could not sell one for less than $50 a quart difference."

If it is in fact true that people would not be willing to eat foods contaminated with a microcurie or so of strontium 90 per kilogram of calcium, then I think we are not going to recover very expeditiously from this war.

It is only because, for a short time, we are willing to eat such food, that I believe our recovery would be rapid. If this is not true, then we are either not going to have food, or we will put much energy into obtaining food that should go into other reconstruction projects.

It is important to realize that world agriculture would soon adjust to this problem. We would find the United States growing nonfood crops and meat and Argentina growing dairy products, and so on. In a relatively short period of time, if there is recovery, the patterns of agriculture will adjust to the contamination, and while food may cost a little bit more, it will not be excessive in either price or contamination.

Therefore, in all likelihood, the Sr^{90} problem is a short-term problem, but it still must be treated objectively and soberly, without any unnecessary panic or hysteria for that first 3, 4, or 5 years. I should also mention that there are other alleviating measures that will help.

I would like to repeat, it is really important that we treat this and other problems ahead of time, because if we do not, and wait until the crisis, we are going to find somebody raising this question, and we will not be able to answer it convincingly on that day. We must have thought this thing through long before the Russians ask us to think it through. Among other reasons, because it has to be debated.

Representative HOLIFIELD. What you are advocating is to take these problems that are imminent and put them on the table, talk them through, and get the most authoritative information on each one now, so people will know what they face?

Mr. KAHN. For this purpose I am not really so much interested in the people, though I have the same interest in them that you have. I am talking about the experts knowing what they face, the men who advise the Government during the crisis. You do not want them panicking. In fact, to be really frank, if there was any way of getting the initial discussion restricted to just 10,000 people, I would like to do it that way.

Representative HOLIFIELD. Why?

Mr. KAHN. I want to get as many technical arguments as possible out of the way before we fill the headlines with them. I prefer these technical arguments occurring not behind closed doors but in the technical arena. Unfortunately we cannot do it that way.

Representative HOLIFIELD. In other words, you believe the scientists should come forward with the scientific information and settle the fights among themselves before submittnig the conclusions to lay people, who are not technically qualified to form judgments. Is that your position?

Mr. KAHN. I don't think that is completely possible in our form of society or even desirable, so I am not recommending it. But if it could be done a little bit like that, I would prefer it.

You do get a lot of misinformation in the headlines, and people do get overly scared, or underly scared. They are entitled to this information, they should have it, but they are not entitled to misinformation or even unsophisticated notions.

Representative HOLIFIED. You are not denying the right of any individual to make any conclusion on the basis of a moral or a philosophical or a spiritual conviction?

Mr. KAHN. Absolutely not.

Representative HOLIFIELD. But what you are saying is that the information should be available for those people who wish to make the basic conclusion on the facts. Then let them apply them in any way they want to, morally, philosophically, or spiritually?

Mr. KAHN. Right. To give you an example of the difference, in the 1957 hearings on fallout, people were talking about things like a fraction of a roentgen. And yet they were using very cataclysmic language. In the current hearings, in reference to much higher amounts, witnesses are always adding words, to the effect, incredible as this is, the country can survive it.

Senator ANDERSON. Has the National Academy of Sciences done anything along this line?

Mr. KAHN. Yes, there is a great deal of information available today. And it is not the technical information that is in dispute, really. It is how you feel about it. What is your attitude toward it? People have not really evaluated this technical information in terms of reasonable postwar standards. This is not a technical decision in the sense of something one learns in school or even in a laboratory. These are things which Congressmen and the public must be involved in. But it is well to get the debate some distance among the experts before it is opened up. That is all I am saying.

Senator ANDERSON. But when the Federation of American Scientists want to talk about this, people say, "Oh, maybe some of them are left-wingers." That is the major difficulty, is it not?

Mr. KAHN. It is one of the major difficulties. I have a paper listing 52 Nobel laureates who signed a statement to the effect: "All nations must come to the decision to renounce force as a final result of policy. If they are not prepared to do this, they will cease to exist." If you look at that list of 52 of our most distinguished scientists, you cannot dismiss them as just a bunch of left-wing radicals making this extreme statement. Most of them are just scientists who have either made or think they have made, seen or think they have seen, calculations which imply just what they said. But the statement is extreme. It says, "All nations," and says, "cease to exist." It does not say "damage." Well, this is the kind of remark you get early in the discussion. It would be better if the statement could have been debated some before it was released.

Now, there is an important point here. I am not saying that a war that occurred in the year 2000, or even in 1975, might not be almost as cataclysmic as this. It is getting worse on a year-by-year basis, and many of my friends tell me, "Herman, you really shouldn't go around saying that people can fight and survive wars, because, after all, 10 or 20 years from now you may be obsolete, and it takes 10 or 20 years to explain things to people, so let's start now."

That is a judgment which I think (a) they have no right to make, and (b) is wrong. These problems of ours must be met on a year-to-year basis. We cannot get to 1975 if we do not get to 1960 and 1965.

Furthermore, no matter what your picture of a future utopia is, and we all have one, or you cannot live in this world, you have to get there, and getting there may be harder than drawing one up.

In other words, we have to be able to meet the challenge as they come on a year-by-year basis. This means we have to understand what the problem is on a year-by-year basis. Transition ararngements are just as important as final states.

Representative HOSMER. Are you not to some extent making an evaluation of what you would have in 1965, or be willing to accept in the way of a world in which to live; in one case if there was a nuclear war, and in the other case if you avoided it by accepting some other alternative, which might produce some comparable situations that were less acceptable than those created by the war?

Mr. KAHN. That is part of what I have been saying. But it is difficult to limit technological progress. Let me give you a feeling of what the future may hold. The public press has referred to bega-

ton bombs, for example. I am not saying such bombs are possible or not possible, but there is no law of physics which says they are not possible. You just cannot limit man's technology, and therefore it might literally be possible for human beings to blow the world into little pieces at some date within our expected lifetime, well within it, maybe. And it is clear that when that instant arrives, if you are going to fight a war at all, you have to fight it carefully, or maybe you cannot fight at all.

Unfortunately, war has had an important role in human institutions for many years now. The regulatory effect of the threat of force has also been important. It is a little hard to believe that all of our problems are going to be solved. It is hard to believe that just because you cannot strike the other person any more, that he will then behave very well.

I would like to emphasize: Britain declared war on Germany in 1914. Britain declared war on Germany in 1939. If they had not been able to declare war in either of those 2 years, they would have had to let the Germans do whatever they wanted to do.

However, it may well be, though, that we will face problems in the near future which are just not solvable by the techniques we have used in the past. In fact, that is true today to some extent. And it may well be that we should start on this new world right now. But it is a mistake to say that the new world has arrived today. It does not seem to be true.

I have a book with me today which I recommend to those who want to exaggerate the impact of thermonuclear war. It is called "Munich: Prologue to Tragedy," by Wheeler Bennet. Among other things Wheeler Bennet discusses why Chamberlain and Daladier folded. When they returned from Munich they were cheered by their people in Paris and London, because war had been averted. Over that weekend some people began to understand that war had been averted by a sellout of the worst sort. And on Monday some few were prepared to criticize. But if you read the debate, you noticed something very significant. The people who criticized Chamberlain and Daladier, with a couple of exceptions, did not criticize them for not going to war; they said, "Hitler was bluffing, and you should have stood your ground."

As far as we can tell, Hitler was not bluffing. The men who were in the room with him could see he was not bluffing. It was easy for the people back home to say he was bluffing, but not for the men who had the decision to make. The German people did not want war. The German Army did not want war. They literally threatened to have a military revolution. But Hitler seems to have been willing to have a war if he couldn't have his way.

We may be asked that same question. If the other man is not bluffing, and he may not be, then we have to ask ourselves, "Are we willing to fight or are we not? Do we have an alternative to peace?" It is just that simple.

Let me mention one more thing about the strontium 90 problem which gives one more reason why people are so concerned.

If you had tried to predict the effects of this kind of contamination before we had carried out these worldwide experiments, the testing in the Pacific and the Soviet Arctic, you would have probably estimated the concentration in new bone as about 10 times larger than it is.

It turns out that the chain which brings Sr^{90} into the human body from the fallout to the grass, to the cow, to the milk, to the intestines, to the bone, discriminates against strontium 90 versus calcium. This is purely fortuitous. Nobody would have predicted it ahead of time. If you had been rather subtle in your calculations, you might have realized this uncertainty existed and taken a factor of 10 against you. That would have made the predicted problem a hundred times worse than it is.

Now, certainly if the problem came up very suddenly in a crisis, and you wanted to make a conservative calculation, you would have taken the 10 against you, and would have predicted a problem 100 times worse than it is, and you would not be talking about A, B, and C foods, but about the abandonment of the country or at least of agriculture. We were just lucky, so to speak.

If you look at the other problems which bother people, the carbon 14 problem, for example, it is not so bad, but it has a similar characteristic. One of the problems that bothers people most about it is that 10,000 years after the war is over carbon 14 will still be causing genetic damage. That is a horrible thing to think of—you have a war today, and 10,000 years from now people are still suffering from the consequences of that war.

But from our point of view that damage, though acceptable over 10,000 years, is much less acceptable if it is taken in, say, 20 years. If carbon 14 had a lifetime of only 20 years, you would be much less willing to face the possibility of a war and more willing to appease. And if it was a really big war you could not face it, because you would be getting thousands of roentgens in one generation rather than 50.

The point I am trying to make is that you cannot say, as people are sometimes tempted to say, that man has faced plenty of things in the past and therefore can face this also, that man always has and therefore always will rise to the occasion. No man can rise to the occasion with a thousand millicuries of strontium 90 in his body or a dose of 3,000 roentgens.

The reason why I and my colleagues feel that the United States or Russia can survive this war is because we have experimental and theoretical data and have made calculations.

To put it in the words of the physicists, there is no conservation theorem which states one can get through this war. It takes data and calculations to show it.

That is a very frightening thing, because that means you are depending on theory. And, as you know, theories have gone astray. Even bridges occasionally fall down.

Now, if you look at the kinds of wars discussed in the last 4 days, there is such a large factor of safety present—and I think some of the testimony was pretty extreme, but most of it was very responsible—you can really feel that you can get through a war in the near future. Nobody today knows whether you could get through a war 30 years from now, even if you spent tens and hundreds of billions of dollars, because the problem may get much worse. We estimate that just to answer some of the relevant questions would cost $200 million. These are complicated questions.

Representative HOSMER. You did make some calculations, I believe; what it would take in time and resources to achieve a return to prewar standards.

Mr. KAHN. Let me do that in just one moment.

I am not trying to say one cannot face wars in the more distant future. I am just saying we do not know. We should find out.

If you look at an attack such as the one this committee looked at, you will find that more than half of the wealth of the country survives the attack. You find that much more than half of the population survives. You find you have a great many resources left over. Many people think of this as a very misleading observation. That is, they think of a human society as being similar to human bodies. If you destroy one vital organ, the body dies. The hair cells might linger on for a while, but eventually everything dies.

Now, that is not our view of society. It is rather interesting that before World War I, many experts had the same view of international trade. They argued that wars had to be short, because nations were so dependent on international trade that if it was cut off they would die. Today we know that this is not true and we use the same international analogy in our study.

We divide the country into two separate countries, an A country composed of, say, the largest 50 to 100 metropolitan areas. (A metropolitan area includes neighboring suburbs.) Then we say there is a B country, the rest of the country, the medium cities, small cities, towns, rural areas.

We notice that the B country has a large population, well over 100 million people, that it has a lot of wealth, that even if the A country was completely destroyed, the B country could probably not only survive that destruction but rebuild the A country in something like 10 years.

Now, we have no faith in that calculation. It is a calculation which nobody knows how to make. But we do not know whether the calculation is optimistic or pessimistic. It is just the best we can do.

My time seems to be running out, so let me finish by making some caveats. For this size of attack I do not know if these caveats are very important, though it would be important for a much larger attack.

We believe that if one dusted the United States with the fallout from this kind of attack and did no other damage than if we had made cheap preparations for attacks of the size studied by the committee and expensive preparations for much larger attacks, we could handle all the radioactivity problems. We believe that if you evacuated the A country and destroyed it totally, these 50 or 100 largest cities, and did nothing else, that we could rebuild these cities in 10 years or so.

We also believe that if you did nothing else but just kill one-third of the population of the United States, the other two-thirds would not commit suicide. They would bury their dead, go into a period of mourning, and then life would go on. It is just that simple.

But there is a very important question which we never even looked at. What if you do all of these things together and do many other things?

Certain data were presented yesterday on ecological effects, these large fires and things like that. I think that data is a little premature.

It probably does not correspond to a war of this sort, but a war maybe 5 or 10 years from now. But still you are doing things like that. You are burning large areas of the country. You are killing more insects than birds, and other things of that nature.

Now, it is our belief, not strongly held, but moderately strongly held, that for an attack this size, these interacting and unlooked at effects will probably not be crucial. For a larger attack, we are certain they are very important and have to be looked at insofar as they can be looked at.

Senator ANDERSON. I asked a very able scientist one time what he thought the outcome of a nuclear war would be. He said, "Well, if you would give me one of the caverns in your State where I can hide one plane and put one bomb in it, I would wait 3 days after the war started, and then I would try to find the one remaining person in the world and kill him with that bomb." He felt it would be total destruction.

You do not think it will be that way?

Mr. KAHN. It is not like that at all, so far as we can tell.

Senator ANDERSON. At Sarajevo there was one little rifle shot, but before we got through there was quite a little shooting.

Mr. KAHN. In the three lectures I try to discuss how wars terminate. This is a very complicated and uncertain subject. But, like anything else, one can conjecture and speculate. As near as I can tell, in most wars one side or the other gets a commanding lead very fast. In other words, you do not go down together. One side gets very much ahead. And then the only question that arises is a variation of the following. The side which is ahead can tell the side which is behind, "Unless you surrender or negotiate, I will physically destroy you. I will literally kill every point of resistance. I prefer you surrendering (a) because I am a humanitarian, (b) because you can hurt me while you are going down and I prefer that you don't hurt me any more than you have." The side which is behind has the choice of trying to use its remaining power of destruction to get a good bargain, but its bargaining position is weak.

Now, if you look at this bargaining in detail, you notice that there is a great pressure of time, communications, control problems. It is a very bizarre world; it is not like an international conference at Geneva. One cannot propose complicated diplomatic formulae. The demands must be very simple. Whether they will be accepted or whether the war will be fought to the bitter end in unpredictable. Once you get into this kind of thing, you can only conjecture what will happen. But one thing seems relatively likely, a war in which both sides go down together and fight it out to the last plane and so on is a very hard war to envisage, if you look at exercises, maps, and the effects of modern weapons. It just does not seem to be like that, for most wars. The only one in which it seems to be possible is one where the war starts accidentally, where no side made any real preparations.

But if one side gets in a very good first strike, it will in all probability, in a very real sense, win the war.

Senator ANDERSON. I am afraid that we are going to have to terminate here.

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Representative HOSMER. Before we do go, I would like to call attention that on page 8 ways and means are spoken of to ameliorate a thermonuclear war. They will be in the printed hearings.

(The prepared statement of Herman Kahn follows:)

MAJOR IMPLICATIONS OF A STUDY OF NUCLEAR WAR[1]

Herman Kahn, Rand Corp.

The general belief persists today that an all-out thermonuclear war would inevitably result in mutual annihilation, and that nothing can be done to make it otherwise. Even those who do not believe in total annihilation often do believe that the shock effect of the casualties, the immediate destruction of wealth, and the long-term deleterious effects of fallout would inevitably jeopardize the survival of civilization.

A study recently carried out by the author and a number of his colleagues at Rand, and privately financed by the Rand Corp., has reached conclusions that seriously question these beliefs.[2] While a thermonuclear war would be a catastrophe—in some ways an unprecedented catastrophe—it would still be limited catastrophe. Even more important, the limits on the magnitude of the catastrophe might be sharply dependent on what prewar measures had been taken. The study suggests that for the next 10 or 15 years, and perhaps for much longer, feasible combinations of military and nonmilitary defense measures can come pretty close to preserving a reasonable semblance of our prewar society.

As long as we think of a thermonuclear war as a sort of end of history, we may not feel acutely uncomfortable about placing all of our reliance either on deterrence or on measures to alleviate tension, as this seems to be all we can do. We may also feel that if war automatically means mutual annihilation surely no one would start one. However, as soon as we realize that it is technically and economically possible to alleviate the consequences of a war, then some of these psychological blocks to consideration of additional actions should disappear. The measures suggested by this study are not substitutes for adequate deterrent forces nor for sensible attempts to alleviate tension. They are insurance against the possible failure of these first priority measures and a complement to them.

Our study was not a large effort. It was done by a team of about 20 professionals, drawn from various fields, who worked an average of four months on this problem. We tried to answer or define all the serious questions about nonmilitary defense. Obviously we could not examine these questions in great depth and detail; thus, the numbers the study produced might well change with further investigation. The results, however, are plausible and should be far better than most intuitive feelings and preconceptions about this critical subject.

DESCRIPTION OF THE POSSIBILITIES

Our analysis has brought forth the following results. While it is suggested that these be re-examined by a more complete study, we have sufficient confidence in them to suggest a $500 million program, described later. Roughly we decided that:

There are a number of combinations of military and nonmilitary measures which could provide valuable levels of protection in a nuclear war. The level of protection depends on the size of the program and the nature and magnitude of the attack. Inexpensive measures designed to insure national survival in an all-out war of the early 1960's might be fairly cheap and relatively reliable—something of the order of a billion dollars or a fraction thereof should be sufficient. More complete programs, designed to protect more than the most easily protected people, would be more expensive. Because such programs cost in the tens of billions of dollars, they are automatically controversial. However, we believe that at least the inexpensive programs should be carried out—so that if a war should occur the majority of our population would not only survive the war but would be able to restore some semblance of prewar society quite rapidly. In a war of the early 1970's, even minimum measures to insure survival might be expensive (in the tens of billions) and probably less reliable. (Cost and

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[1] This paper is a revised version of an article, "How Many Can Be Saved," that appeared in the Bulletin of the Atomic Scientists, vol. XV, No. 1, January 1959.

[2] "Report on a Study of Nonmilitary Defense," the Rand Corp. Rept. R-322-RC, July 1, 1958.

performance change with time because the enemy threat changes.) However, at least a start should be made in preparing such measures.

Oversimplifying a bit, one can say that during this 1960–70 period against a premeditated all-out surprise attack, moderate nonmilitary defense programs, if combined with reasonable military programs, should protect about half the population with high confidence, an additional one-fourth with medium confidence, and a final one-fourth with low confidence. A phased program might start with relatively cheap measures for 1960, develop into a minimum fallout program and then possibly later into a quite adequate or "luxurious" program which included blast shelters. While the planning should be done on this basis, there need be no irrevocable commitments to go ahead with the next phase if for any reason it seemed desirable to slow the program down or stop it.

It should be noted that wars can start in a manner other than a premeditated program and then possibly later into a quite adequate or "luxurious" program might be very effective. Therefore, even if we are not willing to pay the cost for complete preparedness, we might be willing to initiate partial programs. These partial programs could be combined with prewar mobilization capabilities designed to put in an adequate program in a few years if the international situation deteriorates. It is plausible to consider such prewar mobilization capabilities because a country with a gross national product of about $500 billion and a construction industry whose capacity is close to $100 billion can contemplate doing things in a hurry if cheap but time-consuming preliminaries such as those involved in research, development, planning, analysis, design, programing, and legal hurdles have been eliminated.

In addition to protecting people from the immediate effects of the war, it is necessary to insure their survival in the postwar environment and then to restore prewar standards of living if possible. Our study also indicated that:

Shelters with long occupancy time and the use of known anti-contamination techniques should make it possible to handle the acute radiation problem (during the first 3 months) from even severe attacks.

With only moderate preparations in the early period and more elaborate ones in the later, it should be possible to handle short-term (3–24 months) survival, patchup, and repair problems.

Combinations of military and nonmilitary measures could protect enough capital to enable the economy to be restored to about half the prewar levels in the first year. The recuperation to prewar levels might be much faster (5–15 years) than has been generally supposed. In any case, if reasonable measures were taken the economy, on a per capita basis, would in all probability not drop below 1930–40 levels, except perhaps in the first postwar year.

Long-lived radioactivity problems, while serious, could be alleviated to the extent that, in comparison with the direct effects of the war, they would have a relatively minor impact on the economy or personal life of the population. Subject to uncertainties, the same should be true of the genetic effects. Even though these may last for a thousand years, the burden on any single generation should only be a fractional increase over the current normal burden of congenital defects.

IMPLICATIONS FOR DETERRENCE

U.S. national policy rests on a deterrent strategy. Presumably, deterrence of Soviet attack depends upon Soviet calculations of their risks versus their chances of success. Our study distinguishes three types of deterrence in examining the implications of nonmilitary defense:

Type I—Deterrence of a direct attack on the United States. In this case any calculation the Soviets might make would assume they have the first strike and the United States strikes back with a damaged force. (Calculations ignoring the effects of the first strike and therefore based on the preattack inventory of forces can be very misleading.) The Soviets then ask themselves what damage they are likely to suffer before hostilities end. Here the Soviet Union's estimate of the effectiveness of their passive defense preparations may play a crucial role, and the United States should examine these to see what questions they raise. Presumably since the Soviets can count on warning, and because they need only defend themselves against a damaged force, even moderate preparations might be considered effective under some circumstances. It is not that the Soviets could reliably expect to be untouched, but that a situation might arise in which the Soviets might feel that going to war was the least risky of the available alternatives.

U.S. nonmilitary defense programs will probably have only a marginal effect on U.S. type I deterrence. Because the war will almost undoubtedly be short and fought with existing stocks, civilian production and morale are unimportant to the military course of events. The chief importance of U.S. nonmilitary defense in this case resides in more or less accidental byproducts such as protected communications, survival of off-duty personnel, greater ability to improvise and augment SAC-type forces for second and later strikes, and possibly most important of all, a resistance to post-attack blackmail tactics which might otherwise succeede in at least partially disarming our surviving SAC forces.

Type II—Deterrence of extremely provocative behavior. The Soviets now ask themselves if they can force the United States to accept peacefully the consequences of some extremely provocative action (say a large-scale attack on Europe or a Munich-type crisis). They presumably ask themselves, "What is the U.S. risk-gain calculation?"—crediting the United States with the first strike. Under these circumstances, in which there has been a tense situation, the Soviet Union strikes second with a damaged force; and when U.S. warning problems have been simplified, even modest civil defense programs relying mainly on evacuation and improvisation might perform impressively enough to make it clear to the Soviet planner and to our allies that there is a good possibility, if not a certainty, that the United States would not accept the provocation peacefully. If the Soviets were not deterred then the United States might actually carry out an evacuation to try to persuade them to desist. If the evacuation did not persuade the Soviets to desist, then in the last resort the United States might decide that it was less risky to go to war than to acquiesce.

The ability and willingness of the United States to engage in type II deterrence activities will be strongly affected by our type I deterrence capabilities. Because using type II deterrence automatically strains our type I deterrence (particularly if we try the evacuation maneuvers), we now need more of it. Almost all of the remarks made about type II deterrence carry over to our ability to wage and limit "limited wars."

Type II deterrence is, of course, symmetrical. There is an enormous difference in the bargaining ability of a country which can, for example, put its people in a place of safety on 24 hours' notice, and one which cannot. If it is hard for the reader to visualize this, let him imagine a situation where the Russians had prepared for exactly that and we had not. Then let him ask himself how he thinks we would come out at a subsequent Munich-type conference.

Type III—Deterrence of moderately provocative actions. In this case it would be wishful thinking to expect deterrence to work most of the time. However, Soviet calculations which contemplate provoking the United States might be influenced by the existence of a U.S. plan for a crash nonmilitary defense program. If a Soviet provocation touched off such a U.S. program, then the Soviets would probably be forced either to match this program, accept a position of inferiority, or possibly even strike immediately. In all cases, the costs and risks to them of their provocation are increased. If this possibility is made clear and probable, the Soviets should include these costs and risks in their calculations. Our type III deterrence is also affected by Soviet nonmilitary defense programs because their willingness to be aggressive and their bargaining ability may be influenced by the risks they run.

A converse effect may be an important additional bonus of even a modest start toward a realistic U.S. civil defense program. Such a program makes more "rational" a strong foreign policy (when a strong foreign policy might seem desirable) by decreasing the immediate risks. Making a stronger foreign policy more "rational" may or may not make it more probable, but at least it is made more credible. This should help in deterring some minor as well as extreme provocations. Even an explicit mobilization capability can be important because it should make it credible to our allies that we will at least be able to put ourselves soon into a position where we can rationally back them.

IMPACT ON MILITARY MISSIONS

The study made a superficial investigation of the components of nonmilitary defense and their relationship to complete and balanced defense and deterrence systems. For example, nonmilitary defense provides a new perspective for studies of active air defense and offense. Most air defense studies have tried to devise systems to protect the U.S. mobilization base—economic resources and population—with a high level of certainty. Actually, this goal can be made to seem attainable only if unrealistically optimistic assumptions are made. The

result is either a dangerous over-optimism about the power of defense or an equally dangerous apathy and despair. Similar remarks can be made about our strategic offense insofar as it is designed only to deter and not to fight a war. Such viewpoints tend to ignore the very important role our defense and offense systems can have between these two extremes in alleviating the consequences of war.

Because a nuclear war would be horrible, it takes an act of imagination to visualize one starting; but it should not take a further act of imagination to believe that such a war would end. As part of the study we considered various ways in which a war might terminate. If one or both sides were improperly prepared, such a war might end in a few hours by the almost total destruction of the military forces of one side by the other. If, however, both sides had made even moderate (but realistic) preparations to fight a long war—a war of at least a few days duration—then appreciably military forces should be left on both sides after the initial onslaught. And this in turn means that there are advantages to both sides in ending the war by negotiation.

Certain tactics facilitate a quick and favorable end by negotiation. For example, one side can avoid some large fraction of the other side's cities and use the threat of destruction of these cities both as a hostage for the enemy's good behavior and as an inducement to negotiate. Similarly, the other side can adopt a similar tactic and use the threat of his surviving forces to compel the enemy to offer "reasonable" terms. As in classical warfare, the "reserves" may play a central role.

No matter what sequence of events is imagined, the possibility that the offense and defense could survive for some days is important. Nevertheless, most discussions of new strategic systems appear overly concerned with wars that last less than 1 day. If we are seriously interested in alleviating the consequences of a war, then we are interested in having military capabilities—both offensive and defensive—on the second and third days of the war. In fact, sensible military planning would provide for wars lasting from 2 to 30 days, though the first day—or even hours—of the war is still likely to be of the utmost significance.

INTERACTIONS WITH DISARMAMENT

The most obvious effect of civil defense on disarmament is the reduction in the vulnerability of the civilian targets. This has only an indirect effect on the military situation of a potential defender since most civilians and their buildings are not really military targets. However, a reduction in civilian vulnerability may be of major importance in reducing the risk that a potential aggressor faces. Presumably he can contemplate accepting a larger retaliatory strike if he has a reasonable nonmilitary defense program than he could if he didn't have one. To this extent a civil defense program conflicts with some of the objectives of a disarmament program.

There are, however, two very important ways in which civil defense programs may help a disarmament program. First, the civil defense programs make a nation somewhat less vulnerable to blackmail or a breakdown of the disarmament agreement. If a nation is totally vulnerable to an attack, then it is also totally vulnerable to blackmail and the fact that it might be able to destroy the blackmailing nation does not necessarily help. It is just not credible that a nation such as the United States will consciously and deliberately choose suicide while there is any hope of life. In other words, pure disarmament programs without any civil defense make no allowance for type II or type III deterrence. It is extremely wishful thinking to believe that such things will never be necessary. It may be positively dangerous deliberately to weaken our type II or type III deterrence to the point where it is an invitation to a potential aggressor. Furthermore, even a disarmament program will not completely exclude the possibility of accidental or unpremeditated war. Finally, even the best disarmament agreement might be repudiated or violated—possibly initiating a sequence of events which lead to war. It is, therefore, always necessary either to have capabilities to alleviate the consequences of a war or at least to be able to create capabilities in a short period of time. In general, adequate civil defense capabilities cannot be created in a short period of time unless extensive preparations have been made.

A rather important and valuable effect of a realistic civil defense program (and one that is often overlooked) is a psychological one. If one is designing his military establishment to terminate a war, rather than just to deter one (by

punishing the enemy with a retaliatory strike), one is much less likely to indulge in wishful thinking. Even today, without any disarmament schemes, Western military organizations and their governments have psychological and motivational difficulties in maintaining a high operating state of readiness and adequate combat capabilities. This is partly because many feel both that such weapon systems will never be used, and that if they were used they would be so destructive that you don't really care if they operate well or badly. If this attitude is combined with the moral onus on military preparations and planning that a disarmament agreement might bring one could almost confidently predict an undue and possibly dangerous degradation of Western military capabilities. If one is emotionally committed to the belief that deterrence is foolproof, there is not much of a step from being satisfied with a system which is objectively capable of destroying the enemy in a rataliatory blow to a system which can only hurt the enemy, and from there to a system which might hurt the enemy, and finally to one for which there are circumstances in which it is conceivable that the enemy will be hurt. The capacity of Western governments and peoples, under propitious circumstances, to indulge in wishful thinking in the military field is almost unlimited. An official aim which calls for an objective capability to terminate a war in a reasonably satisfactory fashion might have a salutary effect in restraining fancies. (W. W. Marseille has suggested to the author that "this is putting the cart before the horse. The psychological factors are what cause us not to have a realistic civil defense program in the first place." However, the author has found—to his surprise—that once people start thinking in terms of alleviating a war it is possible to successfully make points which it should have been possible to make if one were only arguing deterrence, but which were not taken seriously in this latter context.)

A PROPOSED CIVIL DEFENSE PROGRAM [3]

Once one accepts the proposition that it is possible to alleviate, to some extent, the consequences of a thermonuclear war, one is faced with the question, "Is it worth spending money on such a capability?" [3]

1. The creation of incomplete but worthwhile capabilities by reorienting and strengthening the current civil defense program utilizing feasible evacuation measures, improvised fallout protection, damage control, modest preparations for recuperation and, giving these other measures, the institution of a vigorous program of education and technical assistance to private parties and organizations. Some inexpensive measures might save from 20 to 50 million lives, limit the contingent damage to property, markedly facilitate our ability to recuperate, and provide an environment in which private citizens could do sensible things on their own to increase their chances of survival.

2. Research and development on all important aspects of the art of nonmilitary defense. Unlike research and development on military matters, nonmilitary defense has received comparatively little money and effort. In particular, the little work necessary for this study indicated that imaginative work could not only result in large improvements in the effectiveness of defense measures, but could also uncover many unsuspected problems that would otherwise be very unpleasant surprises.

3. Accompanying the research and development work should be a vigorous effort on the systems design of various combinations of military and nonmilitary defense. This effort should produce specification, including phasing, of many alternative programs. These specifications should be of sufficient detail to permit their costing and their performances to be caluculated over time and under many circumstances. Paper planning and design should be undertaken for a number of the alternatives specified so that any program finally adopted

[3] Most of the material in this section came from the Rand Corp. Report RM2206–RC, "Some Specific Suggestions for Getting Early Nonmilitary Defense Capabilities and Initiating Long-Range Programs," by Herman Kahn et al. That report was originally prepared in the early part of 1958, and was circulated in a limited fashion to various individuals for information and comment. While I have made some minor modifications in the material to correspond to some changes in my viewpoint, there has been no thoroughgoing revision. The dollar recommendations should be thought of as quantitative expressions of intuitive judgments. However, I should also note that I probably have substantially more justification for my estimates than do many official proposals. In any case, these things are so uncertain, and for reasonable programs the overall performance variations with minor changes in allocations are so small, that as citizen, voter, and taxpayer I am prepared to defend the numerical recommendations, even if as an analyst I have to concede that there is incomplete documentation.

would be less costly and have its leadtime reduced (by perhaps 3 to 5 years over conventional methods of proceeding).

4. While it is technically feasible to start a large-scale program of nonmilitary defense now, there are many uncertainties and gaps in our knowledge. After objectives 2 and 3 (research and development and leadtime reducing measures) have been accomplished, the proper balance between military and nonmilitary expenditures can be studied. The Government could then make wiser decisions, and some of the difficulties resulting from a combination of ignorance and uncertainty would be eliminated or decreased. The decision to go ahead or not go ahead with a multi-billion-dollar program should not be made until objectives 2 and 3 have been carried out.

5. There seem to be many possibilities for inexpensive preparatory actions that could result in the creation of important capabilities in the 1965–70 time period. Again, irrespective of any decision to go or not go into a multi-billion-dollar program, these possibilities should be studied; if and when such actions are found desirable they should be put into practice.

A possible allocation for the additional $500 million to be spent on civil defense might go as follows:

1. Radiation meters	[1] $100,000,000
2. Utilization of existing structures for fallout protection	[1] 150,000,000
3. Preliminary phase (including research and development) of a spectrum of shelter programs	75,000,000
4. Movement, damage control, and anticontamination, etc	[1] 75,000,000
5. Systems studies and planning	20,000,000
6. Other research and development	20,000,000
7. Prototype shelters	20,000,000
8. Education and technical assistance	20,000,000
9. Miscellaneous	20,000,000
Total	[1] 500,000,000

[1] Indicates Federal expenditures that would likely be supplemented by non-Federal expenditures stimulated by the program.

The above program can be divided into two parts: a short- and a long-range program, though there is a lot of overlap and joint use in the two programs, which is the reason why we do not budget them separately.

About 60 to 70 percent of the above $500 million would be spent to purchase capabilities that would be useful if a war started in the immediate future. Because the possible gains are so large, I do not believe that it is necessary to justify spending such a relatively small sum of money, even though there are some uncertainties about the performance of the program. The sum of $300 million is very small if it can make the difference between a relatively expeditious recovery for the survivors of a war and one that might not only be slow but could conceivably not occur at all; or if it could buy the kinds of capabilities that would make the difference between the Russians being able or not being able to blackmail us.

About 30 to 40 percent of the $500 million in our proposed budget, or less than $200 million, is allocated to research analysis, development, planning, and design for a spectrum of civil defense programs. This may seem to be a great deal of money to spend on producing pieces of paper and prototypes. But I believe that $200 million is a reasonable sum of money to spend on finding out how best to secure the lives and property of the Nation, and I would regard the proposed research program as a mandatory precondition to the decision to spend or not spend any large sums on passive defense itself.

Is $200 million really an unreasonably large sum? It costs from $50 to $100 million to develop an engine for a military airplane. It costs $100 to $200 million to develop an interceptor aircraft and $500 million to $1 billion to develop an intercontinental bomber. The ICBM development program cost between $1 and $2 billion. The Department of Defense spends $5 billion every year on research and development. We are saying that a complete nonmilitary defense program is at least as complicated as an interceptor aircraft.

We should also ask if $200 million is too little to be spending on long-range programs. Some people suggest the immediate initiation of large-scale passive defense programs that would cost in the neighborhood of $25 billion. It is improbable that very large sums could be spent efficiently on construction in the next year or two, and it is almost certain that if the attempt were made

without a prior program of the sort we are suggesting that not only would the wrong sorts of personal protection be procured, but there would also be major, maybe disastrous, inadequacies and lacunæ in the overall program..

We should consider the initiation of some inexpensive measures during the course of, and based on the results of, the research program. For example, circumstances might suggest a large "Starter Set"—including procurement of such materials as appear most likely to cause bottlenecks in a larger program: reinforcing steel, corrugated steel, structural steel, cement, and other building materials. If this were done, there would be no lag in the completion date of even the largest programs even though no major construction were begun immediately.

A decision to go ahead or not go ahead on a multibillion-dollar program should be made sepaartely from and subsequent to the completion of the proposed $200 million research program.

Still addressing ourselves for the moment to the proponents of large programs, there is at least one good reason why the Government may now be loathe to make a commitment for shelters. The shelter program itself has been looked at in only a superficial way, and many of the other problems associated with preserving a civilization and a standard of living have not been looked at even superficially. While our study tried to look at these overall problems and, in particular, to ask the question, "How does the country look 5 or 10 years after the war as a function of our preparations?" we scarcely scratched the surface. We believe we have shown that it is plausible, at least in the immediate future, that with inexpensive measures the United States could be an acceptable place to live even a year after the war. However, we concede that the uncertainties are large enough to raise the question of sheer survival, and the problem gets more severe in the later time period. Until the feasibility of recovery and other long-term problems and their solution are settled, it will be hard to arouse real interest in attempts to alleviate the consequences of war. But it is possible to settle these questions relatively inexpensively and at the same time avoid delaying the completion date for a full program or the immediate acquisition of moderate capabilities. The $200 million of our civil defense budget should be spent over a period of 2 or 3 years on what might be called the "cheap" starter set—the preliminary phases of a civil defense program—mostly on research, development, analysis, planning, and design.

These preliminaries should not be restricted to any prechosen program. The scale of the final program will presumably be determined by the results of these investigations and the current international situation; it should not be fixed prematurely. It is also most important to consider explicitly time period in the late sixties and early seventies. Unless we start soon the long-range programs needed to ameliorate the effects of potentially very destructive attacks of this time period, we will find that we have irrevocably lost very valuable opportunities.

Our goal in allocating funds to projects was not that every dollar be spent economically, but rather to make sure that every subject be covered adequately. While we were generous, we tried to refrain from padding. Although our figure of $200 million is, of course, only approximate, it is as likely to be low as high if an adequate job of research, development, systems analysis, planning, and design is to be undertaken. Many of the potential civil defense programs are so expensive that it is worthwhile to spend some money speculatively if there is any chance at all of the overall program being helped by even a small percentage. Therefore, the aim should not be to see that every dime is spent on the assurance that it will result in a successful project, but rather to see that all interesting avenues are explored. Otherwise, there may be disastrous inadequacies or even complete lacunae in the program that is finally adopted.

Such a large and many-sided program of study, planning, and innovation require a strong monitoring effort of a sort that is not common in most Government agencies. This effort has to be much more than the ordinary R. & D. administration. The monitors must maintain a continuous and close observation of all the programs and constantly evaluate their direction and results. While they should be able to suggest the termination of fruitless programs, their main purpose should be to encourage the expansion of promising effort. Most important, they must be alert to identify gaps and inadequacies in the programs, and suggest remedial action.

Because of their crucial role, the monitors must obviously be an exceptionally competent and well-informed group of people. However, the monitors do not need and should not have the authority to orient all programs toward prede-

termined objectives. Experience has shown that attempts to conduct large and overcoordinated programs tend to create inflexibility and to stifle new, unproven ideas or independent approaches. Hence, the monitors should act as an advisory group rather than as a "research czar." But they must have the authority to make suggestions and offer criticism at all levels and have the right to contact the researchers or planners in the field.

The monitoring group could be located in the independent long-range planning organization, mentioned in chapter 2, part II, and act for the various Government agencies that will be principally concerned with the nonmilitary defense effort. Or, it could be a special group in OCDM or under the Presidential assistant for national security affairs. In order to maintain a good "feel" for the program as a whole and to foresee future requirements, the monitors should be closely associated with the systems analysis and operations research program. Perhaps they should also have direct access to funds for small studies or pilot projects.

THE FULL PROGRAM

A superficial description of the $500 million program follows. Somewhat more detail (of a very similar program) can be found in the previously mentioned Rand Corp. report, RM 2206–RC.

1. Radiation meters ($100 million)

Our program calls for 2 million dose-rate meters (at about $20 a meter), 10 million self-reading dosimeters (at about $5 a meter, including an allowance for chargers), and 20 to 50 million dosimeters (at about $1 to $2 a meter).

Only a portion of the meters would be distributed before hostilities. The rest would not be distributed until a "national emergency" occurred or until the postattack period, and they should be stored with this in mind. The final distribution of meters might go somewhat as follows: 500,000 dose-rate or survey meters to the large shelters (capable of sheltering more than, say, 50 persons); 1 million to outdoor workers of various types, such as farmers, prospectors, foresters, construction workers, and so on; 250,000 to individuals and organizations in various towns and cities;[4] and 250,000 to the working teams discussed below under item 4.

The self-reading dosimeters would be distributed approximately as follows: 2,500,000 to the work parties discussed under 4 below; 2,500,000 to the shelters, schools, and other places; and 5 million to the people who work out-of-doors in possibly uncontrolled environments. The $1 and $2 dosimeters would be issued to everybody who is in an even moderately hot area and is not working under completely controlled conditions. The total budget allocated above is more than $100 million, but we think the number of meters suggested could be obtained and distributed if the Government were to allocate only $100 million. The rest of the budget should be made up of stimulated expenditures for meters by local governments, private groups, and individuals.

2. Utilization of existing structures for fallout protection ($150 million)

We would expect about $50 million to be spent on identifying, counting, and labeling the various structures that either provide valuable levels of fallout protection as they now stand or that can easily be modified to do so. The rest of the money would be spent for such supplies as radios, minimal toilet equipment (such things as primitive as buckets), and possibly even minimum food supplies (candy bars, multipurpose foods and such), or materials for improving the protection of the shelter. The survey should include places that can be used as improvised fallout shelters with various amounts of advance warning—1 hour, 2 hours, 4 hours, 8 hours, 16 hours, 2 days, 2 weeks, and even longer. We should hope to get detailed plans for the different kinds of improvisations that are pissible as a function of the time which is available.

3. Preliminary phase (including research and development) of a spectrum of shelter programs ($75 million)

One of the most short-sighted things that OCDM has done is to reduce its expenditures on the study of blast shelters—just because it is not part of the current "national shelter policy" to have blast shelters. As I have tried to stress in these lectures, we just do not know today what we will want 5 or 10 years from now, and current programs and requirements should not overinfluence

[4] Something like this is being done by OCDM.

current research and development. We should not prejudge these unknown future desires of ours by not undertaking inexpensive preliminary work on many more things than we expect to procure. It is only by having a broad base of research and development that we can expected to understand our problems and be in a position to have a flexible procurement policy.

These last remarks have special point for research and development and even preliminary programing in the shelter field. It is clear that if the international situation had already deteriorated to the point where we felt there was a high probability that we would have to fight a war, we would be instituting a very luxurious shelter system, indeed. It may turn out that, given the possibilities for weapons development, a pure fallout system will not be adequate in the late sixties and early seventies. For these and other reasons, the shelter studies should investigate the many different levels of protection that would be compatible with programs of as low as $2 or $3 billion to programs as high as $200 billion.

A possible allocation for the $75 million we have allotted to shelters would be as follows:

Theoretical work in the response of structures	$1,000,000
Theoretical work in design	1,000,000
Basic designs	3,000,000
Experimental testing	15,000,000
Detailed study of:	
10 large cities	10,000,000
10 medium cities	5,000,000
10 towns and rural areas	5,000,000
Study of geology and underground possibilities	10,000,000
Study of nonpersonnel shelters	10,000,000
Special equipment	10,000,000
Miscellaneous	5,000,000
Total	75,000,000

4. Movement, damage control, anticontamination ($75 million)

The two main things we should hope to provide under this category are the capability to evacuate to improvised protection and the creation of a core of "reservists" that would be organized to facilitate the evacuation, the improvisation of shelters either pre- or post-attack, and that would also be useful in the immediate postattack and longer run rescue, decontamination, debris clearing, continuity of government, housing, and repair problems. There are at least 5 million people in the United States who have the proper skills for such work. We should sign up 200,000 of these people as part-time but paid cadres and many others as unpaid part-time cadres or just available volunteers. The 200,000 people might go through a 1-week or 2-week training course every year. In wartime, or in a tense preattack situation, we should plan to expand them by a factor of 5 to 20. Such an organization would probably cost about $500 per man per year, or about $100 million per year for 200,000 people. However, it would be practically impossible to spend more than $25 to $50 million in the first year or two when this group is being organized, and this is the amount in our budget. This cadre might be supplemented (or replaced) by the military reserves.

Another $25 to $50 million would go for all the measures that are needed to create different kinds of potentially useful evacuation capabilities. What money is left, probably around $10 to $30 million, would be used to study and implement the damage control measures that will be necessary to limit the bonus damage when cities, factories, and homes are abandoned, to control fires, and to provide some additional protection for some government or crucial commercial stocks. This last figure is very definitely an allotment and not an estimate.

5. Systems studies and planning ($20 million)

The program described to this point is composed mainly of interim measures that are intended to fill the gap until we can decide what our long-range plans should be.

Among the first things to be studied and planned for are the different kinds of nonmilitary defense systems needed for various situations, and how we can build in our programs large degrees of flexibility. We must design systems to be in a position to exploit favorable circumstances and to hedge against unfavorable ones. Probably the worst defect of civil defense planning today is that it tends to concentrate on a single set of assumptions and circumstances (a surprise

attack directed at civilians), a set that also happens to be the most difficult to handle. As a result, civil defense recommendations have not been tested against a large number of possibilities. The proposed plans should not only consider a large range of circumstances, they should also consider phasing problems so that we will get early capabilities and still be able to accommodate growth in the future—particularly growth required by either unexpectedly large threats or higher standards. Some of the situations that might be studied are listed below:

(*a*) Movement of the population to shelters, considering warnings of minutes, 1 to 3 hours, 10 to 20 hours, and strategic evacuation.

(*b*) The various attack-response patterns (suggested in the lectures).

(*c*) Enemy tactics corresponding to three possible enemy target objectives: military, population, and recuperation—or mixtures of these.

(*d*) Civil defense postures as influenced or determined by many things, including variations in our own or enemy objectives, budget levels and allocations, disarmament, degrees of tension, changes in NATO, Chinese developments, other Russian satellite developments, and so on.

(*e*) Other strategic and tactical considerations; for example, sneak attacks and other unconventional tactics, unconventional weapons, reattacks, and various ways that war can be terminated.

(*f*) Worldwide planning.

(*g*) Basic technical uncertainties to be studied and allowed for include the performance and effects of weapons, carriers, air defense systems, medical unknowns, and so on.

In addition, all studies should be conducted with an eye to understanding and exploiting interactions between military and nonmilitary defenses. Some areas in which these interactions occur, and some proposed research projects, are listed below:

(*a*) The circumstances in which wars can start should be examined to determine what roles can be played by augmentation abilities brought into play in tense situations, on D-day, or even after D-day. For the starter set our military prewar mobilization capability is important. Lastly, and most important, we must reexamine our capability of fighting for days or weeks.

(*b*) Civil defense contributes to the overall problem by reducing the job of air defense and air offense to manageable proportions: by making large military budgets more acceptable (fighting and winning a war takes more military power than is needed for pure deterrence); by making safer use of nuclear weapons in air defense; and by protecting important elements of our air defense and air offense capabilities.

(*c*) On the military side, air defense provides warning, increases the enemy's raid-size requirements (even for minimum-objective attacks), forces him to use expensive carriers and tactics, cuts down his force, decreases his bombing accuracy, and may provide time against ICBM attacks by killing the first few missiles so people can get into shelters.

(*d*) Air offense (and effective civil defense) forces the enemy to buy expensive defenses (by making a U.S. first-strike credible), draws his attacks (particularly his first strike) away from population and recuperation targets, ends the war quickly either by destroying the enemy or forcing him to negotiate, and complicates the enemy's job by being dispersed, hard, and alert.

It might be appropriate at this point to comment on some of the characteristics of good analyses and plans. The following is quoted from RM-1829[5] "Techniques of Systems Analysis," by Herman Kahn and Irwin Mann.

"An item of equipment cannot be fully analyzed in isolation; frequently its interaction with the entire environment, including other equipment, has to be considered. The art of systems analysis is born of this fact; systems demand analysis as systems.

"Systems are analyzed with the intention of describing, evaluating, improving, and comparing with other systems. In the early days many people naively thought that this last meant picking a single definite quantitative measure of effectiveness, finding a best set of assumptions, and then using modern mathematics and high speed computers to carry out the computations. Often their professional bias led them to believe that the central issues revolved around what kind of mathematics to use and how to use the computer.

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[5] A Rand Corp. report.

"With some exceptions, the early picture was illusory. First, there is the trivial point that even modern techniques are not usually powerful enough to treat even simple practical problems without great simplification and idealization. The ability and knowledge necessary to do this simplification and idealization is not always standard equipment of scientists and mathematicians or even of their practical military collaborators.

"Much more important, the concept of a simple optimizing calculation ignores the central role of uncertainty. The uncertainty arises not only because we do not actually know what we have (much less what the enemy has) or what is going to happen, but also because we cannot agree on what we are trying to do.

"In practice, three kinds of uncertainty can be distinguished:

"1. Statistical uncertainty.

"2. Real uncertainty.

"3. Uncertainty about the enemy's actions.

"We will mention each of these uncertainties in turn.

"*Statistical uncertainty.*—This is the kind of uncertainty that pertains to fluctuation phenomena and random variables. It is the uncertainty associated with 'honest' gambling devices. There are almost no conceptual difficulties in treating it—it merely makes the problems computationally more complicated.

"*Real uncertainty.*—This is the uncertainty that arises from the fact that people believe different assumptions, have different tastes (and therefore objectives), and are, more often than not, ignorant. It has been argued by scholars that any single individual can, perhaps, treat this uncertainty as being identical to the statistical uncertainty mentioned above, but it is in general impossible for a group to do this in any satisfactory way.[6] For example, it is possible for individuals to assign subjectively evaluated numbers to such things as the probability of war or the probability of success of a research program, but there is typically no way of getting a useful consensus on these numbers. Usually, the best that can be done is to set limits between which most reasonable people agree the probabilities lie.

"The fact that people have different objectives has almost the same conceptual effect on the design of a socially satisfactory system as the disagreement about empirical assumptions. People value differently, for example, deterring a war as opposed to winning it, or alleviating its consequences if deterrence fails; they ascribe different values to human lives (some even differentiate between different categories of human lives, such as civilian and military, or friendly, neutral, and enemy), future preparedness versus present, preparedness versus current standard of living, aggressive versus defensive policies, etc. Our category, 'real uncertainty,' covers differences in objectives as well as differences in assumptions.

"The treatment of real uncertainty is somewhat controversial, but we believe actually fairly well understood practically. It is handled mainly by what we call contingency design

"*Uncertainty due to enemy reaction.*—This uncertainty is a curious and baffling mixture of statistical and real uncertainty, complicated by the fact that we are playing a non-zero-sum game.[7] It is often very difficult to treat satisfactorily. A reasonable guiding principle seems to be (at least for a rich country), to compromise designs so as to be prepared for the possibility that the enemy is bright, knowledgeable, and malevolent, and yet be able to exploit the situation if the enemy fails in any of these qualities.

"To be specific:

"To assume that the enemy is bright means giving him the freedom (for the purpose of analysis) to use the resources he has in the way that is best for him, even if you do not think he is smart enough to do so.

"To assume that he is knowledgeable means giving the enemy credit for knowing your weaknesses if he could have found out about them by using reasonable effort. You should be willing to do this even though you yourself have just learned about these weaknesses.

"To assume that the enemy is malevolent means that you will at least look at the case where the enemy does what is worst for you, even though it may

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[6] "The Foundations of Statistics," by L. J. Savage; "Social Choice and Individual Values," by K. J. Arrow.

[7] The terminology "non-zero-sum game," refers to any conflict situation where there are gains to be achieved if the contenders cooperate. Among other things, this introduces the possibilities of implicit or explicit bargaining between the two contenders. The whole concept of deterrence comes out of the notion that the game we are playing with Russia is non-zero-sum.

not be rational for him to do this. This is sometimes an awful prospect and, in addition, plainly pessimistic, so one may wish to design against a 'rational' rather than a malevolent enemy; but as much as possible, one should carry some insurance against the latter possibility."

6. Other research and development ($20 million)

This is for miscellaneous research in the medical, biological, food, agricultural, anti-contamination, and fallout areas. The AEC currently spends about the allotted sum every year to study the inherently simpler problem of peacetime fallout from tests. The equally important special wartime problems are mostly being neglected.

7. Prototype shelters ($20 million)

We would suggest building about 10 million dollars' worth of large shelters which, if economically feasible, might include some peacetime functions. In addition to "customary" shelters, this program should include more elaborate shelters and high overpressure shelters. The other $10 million should go for private family-type shelters, running an average of, say, $1,000 apiece. This should enable us to build 10,000 shelters, or 1 for every 20,000 people. This means that every town in the United States would have at least one prototype shelter.

8. Education and technical assistance ($25 million)

It is one of the major objectives of the above program to create an environment in which private citizens and organizations can do sensible things on their own. The main way the Government can encourage this is to do enough on its own so that people will see that if they supplement the Government's efforts they will either improve their chances for survival or the style in which they survive. Many of the preceding suggestions are aimed at making it possible for the Government to furnish realistic technical information and planning assumptions. This will enable those that wish to, to do sensible things on their own.

We feel that at least part of the present apathy in the United States is due to ignorance of what can be done or to doubt that anything can be done. This apathy is intensified by the inadequacy of official pamphlets. The problem does not result from security restrictions or inadequate releases of information; official studies themselves are inadequate. Better studies and more definitive Government programs are needed. Realistic long-range planning, such as we are proposing, would go far toward restoring public confidence in the merits of Government plans and suggestions. Even more effectively, the institution of the "cheap" program, which depends mainly on improvised fallout shelters, would encourage many to build more adequate shelters on their own. As long as there is no reasonable overall program, few will undertake private actions.

In addition to general information, the Government should offer to share some of the private expenses. However, because of the small size of the program, the Government should not contribute anything toward private projects unless it gets a great deal of leverage for its money. One of the easiest ways to get such leverage would be for the Government to spend small sums of money on the preliminary phases of the private projects; that is, it should be willing to go to a private company with a complete set of blueprints showing that company what it would have to do if it participated in a serious way in such a program. This would enable the company, without spending any of its own money or much energy, to get very specific ideas of the cost and performance of its own program. It would help eliminate the inertia that might otherwise prevent companies from initiating any actions. The Government should do similar things for private persons, not only by furnishing complete blueprints for either the modification of existing buildings or for the incorporation of protection in new buildings but also by offering technical assistance in their construction. It should also furnish services to architects, engineers, and others.

In addition to helping private companies and individuals, the Government should try to elicit as much help from the nongovernmental part of our society as it can. For example, once the research program has provided some indication of what a reasonable passive defense program should involve, the Government should enlist the help of private professional groups to expedite some of the

necessary intellectual and technical developments. Some of the organizations whose aid might be solicited include:

American Society for Civil Engineers.
American Concrete Institute.
American Bar Association.
American Medical Association.
American Institute of Architects.
National Planning Association.
Committee for Economic Development.
Chambers of commerce.
National Bureau of Economic Research.
American Association of Railroads.
American Society for Testing of Materials.
American Society for Mechanical Engineers.
American Society for Electrical Engineers.
American Society for Heating and Ventilating.
National Association of Manufacturers.

In the past, private groups have sometimes put time and energy into studies for the Government, but a lack of adequate orientation has often meant that their studies were obsolete before they were started. It is important, both for the morale of the participants and the usefulness of their product, that realistic environments and planning assumptions be given to such groups. For example, the American Society of Civil Engineers (ASCE) is reported to be considering a standard for the protection of buildings in large cities on the order of 5 to 10 pounds per square inch. Such buildings might not be useless in some situations, but they would certainly be useless if bombs dropped nearby. We would propose that a much more useful activity for the ASCE would be to look at joint-use, blast-resistant construction for small cities and rural areas rather than for large cities. An even more useful thing, and one which we would urge be done with a high priority, would be to look at the possibilities for joint-use fallout protection, both with and without warning (hours or days). For example, buildings might be built to use sandbags or fillable shutters that could be put up at the last moment. Either of these would greatly decrease their vulnerability to radiation. We feel that the possibilities are so promising that an appreciable portion of an expensive fallout program might be saved (though only a portion). It is clear there are many other examples where private organizations could be useful. Universities and foundations, for example, could make major contributions.

It is with some reluctance that I include education in the program. This is not because education is not a very important thing. In particular, in a program that depends a great deal on improvising existing assets, it is probably very important for many people to understand reasonably well what they should do. However, the Government has a tendency to try to depend upon education and paper plans to do everything, rather than to spend even small sums for capabilities that would make the educational program realistic and useful. It is not going to be true that our society can be preserved in a war by individual action supplemented only by Government pamphlets and paper plans. I suspect that the major educational impact will come, not from the formal program of information or propaganda, but simply from the impact of the Government's allotting reasonably large resources to a program that it is willing to defend intellectually. This alone should make many people understand that the program is a serious effort and that one does not have to be a "crackpot" or "wishful thinker" to join in. Conversely, if the Government tries to accomplish this program by education alone, if it is unwilling itself to invest a few hundred million dollars and thereby shows that it has little confidence in the effort, then, I think, we should not be surprised if the program fails completely.

It may, of course, turn out that the Government does not wish to engage in a program as ambitious as the one described, modest as it may seem to those of us in the planning field. In that case, we suggest that the Government try at least the following:

1. Reorient Government planning, both military and nonmilitary, to the proper kind of short and long wars; in particular, make explicit preparations for improvising preattack and postattack capabilities.
2. Reorient current stockpile programs to contribute to postwar survival recuperation.
3. Reorient and strengthen civil defense programs to pay particular attention to those situations in which their capability is most applicable rather than try to handle all problems across the board.

4. Broaden the current programs of research, development, and systems analysis to consider in more detail the problems involved in recuperation and in the postwar period generally.
5. Study and propose legislation now to facilitate postwar economic stabilization and recuperation.
6. Initiate research and study in the use of mines as personnel and industrial shelters.
7. Initiate a program of technical education and assistance to orient and encourage private actions planning and research.
8. Do much more long-range planning in the field of nonmilitary defense and independent and dependent groups. In particular, we suggest that OCDM or the executive department establish a permanent long-range planning organization of the same type as Rand, ORO, or the like.

THREE LECTURES ON THERMONUCLEAR WAR (1960–75) BY HERMAN KAHN

LECTURE I. THE NATURE AND IMPACT OF VARIOUS KINDS OF THERMONUCLEAR WARS

This lecture asks the question, "Is it really true that only an insane man would initiate a thermonuclear war or are there circumstances in which the leaders of a country might rationally decide that war is preferable to any of its alternatives?"

It is concluded that there are plausible, even probable, circumstances in which a country may rationally decide on war as its best alternative. In arriving at this conclusion it is convenient to examine eight distinct phases of a thermonuclear war.

1. Various phased programs for deterrence and defense and their relations to foreign policy.
2. Wartime performance with different preattack and attack conditions.
3. The acute fallout problems.
4. Survival and patchup.
5. Maintenance of economic momentum.
6. Long-term recuperation.
7. Long-term medical problems.
8. Genetic problems.

LECTURE II. THE FORMULATION AND TESTING OF STRATEGIC OBJECTIVES AND WAR PLANS

This lecture asks such questions as, "Why and how might a thermonuclear war be initiated? How might it be fought and terminated?"

In discussing these questions it is desirable to distinguish at least three kinds of deterrence:

Type I—The deterrence of direct attack (passive deterrence)
Type II—The deterrence of extreme provocations (active deterrence)
Type III—The deterrence of moderate provocations (tit for tat deterrence)

The requirements for the three kinds of deterrence, their interactions, some of the strains to which they might be subjected, and the probability and possible consequences of failure are discussed. Finally, criteria are set up for different circumstances and objectives to be used in the design and testing of the composition and posture of strategic forces. These are listed below:

Seven basic situations:
- A. Nontense:
  - 1. Premeditated Soviet attack
  - 2. Unpremeditated war
- B. Tense:
  - 1. Premeditated Soviet attack
  - 2. Unpremeditated war
  - 3. Premeditated U.S. attack
- C. Mobilization and legacy
- D. Arms control and violation

Attackers' objectives:
- A. Limit damage
  - 1. Counter force
  - 2. Postattack blackmail
  - 3. Civil and air defense
- B. in war
- C. in peace

Peacetime objectives:
- A. Type 1 deterrence
  1. Quality needed
  2. Second strike capability
  3. Attackers' defense
- B. Type 2 deterrence
  1. Necessity
  2. First strike capability
  3. Non-alert capability
- C. Not look or be too dangerous
  1. To us
  2. To allies
  3. To neutrals
  4. To enemy

Defenders' objectives:
- A. Punish enemy
  1. Priority affected by damage accepted
  2. Population and recuperation targets
- B. Stalemate war
  1. Conflicts with punish enemy
  2. Requires staying power
  3. Feasibility varies
- C. Limit damage

LECTURE III. WORLD WAR I THROUGH WORLD WAR VIII

Some characteristics of eight wars, real or hypothetical, are analyzed, partly to show relations between strategy, tactics, and technology; and partly to illustrate certain historical themes or possibilities. The eight wars, each a technological revolution ahead of its predecessor, are assumed to have occurred as follows: 1914, 1939, 1951, 1956, 1961, 1965, 1969, and 1973. The historical themes associated with each war are listed below:

1914—An accident prone world miscalculates. Expectations are shattered.

1939—Type II and type III deterrence fail. Expectations are shattered.

1951—A militarily superior nation risks disaster.

1956—Type II deterrence wanes.

1961—The Soviet Union attains "parity." Type II deterrence disappears. Type I deterrence is marginal.

1965—The prematureness of "Minimum deterrence."

1969—Possibility and consequences of "Minimum deterrence." Arms control or "?"

1973—Fourteen years of progress (or 50,000 buttons).

Senator ANDERSON. I think it has been a most interesting discussion. We will resume the afternoon session at 2 p.m., in this room, with testimony from Commissioner Willard F. Libby of the Atomic Energy Commission on emergency protection measures.

Following his testimony there will be a panel of the following individuals who will discuss the strategic implications of deterrence: Dr. Willard F. Libby, Comissioner, U.S. AEC; Mr. Robert Corsbie, Director of Civilian Effects Test Group, AEC; Dr. Paul Tompkins, NRDL; Mr. Herman Kahn; Mr. W. E. Strope, NRDL.

I hope you can be here at 2 o'clock.

Mr. KAHN. Thank you, sir.

(Whereupon, at 12:30 p.m., the hearing was recessed, to reconvene the same afternoon at 2 p.m.)

AFTERNOON SESSION

Chairman HOLIFIELD. The committee will be in order.

Just before the noon recess we heard from Mr. Herman Kahn, who testified in advance of his position on the agenda in order to accom-

modate Dr. Willard F. Libby, U.S. Atomic Energy Commissioner, who will speak to us on the subject of emergency protection measures.

After Dr. Libby's testimony is heard and the question and answer period we will have a panel discussion on the strategic implications of deterrents. On that panel we will have Dr. Libby, Dr. Robert Corsbie, Director of Civil Effects Test Group, Dr. Paul Tompkins, Naval Radiation Laboratory, Mr. Herman Kahn and Mr. W. E. Strope of the Navy Radiological Defense Laboratory.

At this time Dr. Libby, I think the Chair should say a few words. You have served as Atomic Energy Commissioner now since the 5th of October 1954. Your term is expiring on June 30 and you have told me that you are going out to my State of California and teach chemistry out there in the University of California at Los Angeles.

Dr. LIBBY. That's right, Mr. Holifield.

Chairman HOLIFIELD. This committee has had you before it many, many times. You have testified many hours. There have been times when some of the members at least have disagreed with you, but most of the time I think most of the members agreed with you. But whether it was agreement or disagreement, our exchange of views has always been pleasant. We realize it is your own desire to return to the atmosphere of the campus again. However, it would be remiss on my part if I did not express, and I believe I am expressing the feelings of all the members of the Joint Committee on Atomic Energy, our thanks to you and our deep appreciation for the many years you have served in the position of Atomic Energy Commissioner, for the untiring effort and the many contributions you have made to the understanding of the American people in this highly complicated and technical field.

So as you go into private life, the good wishes of this committee go with you. We wish you the very best and we are happy that we have had an opportunity to have you once again before us to testify on something which I know is dear to your heart.

Mr. Vice Chairman?

Representative DURHAM. Mr. Chairman, I want to concur first in the statement of the chairman of the subcommittee and also to say to Dr. Libby I think he has rendered valuable service to the American people over the years he has served as Commissioner. Certainly he has enlightened this committee. He is a great scientist. About the only exception I would take to your statement, Mr. Chairman Holifield, would be that my desire would be that he go to my State and my own city of Chapel Hill to impart the information that he has in that great brain of his to students. Of course, I am sure that California will benefit from his presence there. We will miss you, Dr. Libby.

STATEMENT OF DR. WILLARD F. LIBBY,[1] COMMISSIONER, U.S. ATOMIC ENERGY COMMISSION

Dr. LIBBY. Thank you, Mr. Holifield and Mr. Durham. I hope that if there is ever anything I can do for the committee you won't hesitate to ask me.

[1] Date and place of birth: December 17, 1908, Grand Valley, Colo. Education: Bachelor of science, University of California, 1931; doctor of philosophy (chemistry), University of California, 1933; Work history: Instructor of chemistry, University of California, 1933–38; assistant professor, 1939–43; associate professor, 1943–45; professor instructor nuclear studies, Chicago, 1945–54; member, General Advisory Commission, AEC, 1950–54; member AEC, 1954—.

Representative PRICE. Mr. Chairman?

Chairman HOLIFIELD. Mr. Price.

Representative PRICE. If the other members fail to say anything Dr. Libby, it is only because they agree fully with the statement of the chairman and Mr. Durham.

Representative HOSMER. I wish to concur in that completely. It goes almost without saying, our respect for your integrity, for your knowledge and for the wisdom of the advice that you have generously offered us.

We all wish you the best of luck.

Dr. LIBBY. Thank you, sir.

Representative HOSMER. I am particularly delighted because you are coming out to my part of the country as well as Mr. Holifield's.

Dr. LIBBY. Thank you, Mr. Hosmer.

Chairman HOLIFIELD. You may proceed, Doctor.

Dr. LIBBY. Mr. Chairman, in the testimony before this subcommittee you have been informed on the effects of a simulated attack on our Nation with nuclear weapons delivered by modern military methods.

The things an attack like this can do to us, the extent and the nature of the effects on people, livestock, crops and on our educational, social and governmental institutions call for energetic leadership and action.

A million of anything is a lot. When we estimate casualties in the millions, it is obvious that we face a possibility which requires priority attention.

There are relatively simple things we can do in preparation for the time of disaster which will make a tremendous difference in our response as individuals and as a nation.

The most effective way to reduce war casualties is to not have the war; and the national policy is to work continually toward conditions which lead to a lasting, just peace for all men.

We are led, when we review the history of man, ancient and modern, to the conclusion that it is wise to take out some insurance for our protection in the event that something goes wrong and peaceful international relations come to an end.

The nature of the effects of modern nuclear weapons and the ranges over which these effects can produce casualties may provoke the question: "Is there really anything we can do?" My answer to this question is, "Yes."

Now I am not going to sit here and tell you that there is a simple, cheap way to protect the people who are in the center of a target at the time it receives a direct hit.

If the weapon is large and accurately delivered, the closein results of the detonation are pretty well fixed.

But let us talk of the people located beyond the range of the initial effects. These people live everywhere in the Nation, in large towns and small, on the farms in rural areas.

We must remember that they also live in our large cities. All have available to them the courses of action which will increase the probability of their surviving and decrease the probability of their becoming sick or being injured.

The committee will recall that we have announced that the fallout from the March 1, 1954, detonation at Bikini Atoll would have created radiation casualties in an area estimated at 7,000 square miles if no protective measures were taken.

Casualties, seriously injured, and dead from the initial effects of this bomb would have occurred in an area of perhaps 250 to 300 square miles.

There is a great difference between the two areas and I should like to focus attention on the need for protection and the capability for protecting the people in the 6,700 square miles or more beyond the range of initial blast, thermal and nuclear radiation. We can save them easily. We can lose them easily.

As a case in point we may think of an attack on a hardened military installation in a sparsely populated area. The initial effects may inflict heavy damage on the facility and military implements.

The number of personnel casualties may be relatively low in number. But for hundreds of miles downwind—assuming surface bursts—the residual radiation will injure or kill those who are unprepared.

Thus a more densely populated area of little true military significance may find itself involved with the results of events occurring hours earlier many miles away.

That fact that you don't live in or near a potential target no longer gives you the sense of security you might have had when only conventional explosives were used.

And of course you have no control over the selection of targets.

Now what can we do?

The first action for anyone who does not already possess the knowledge is to learn what these weapons effects are. No one can be expected to act properly or at all for that matter on any problem unless he understands what makes it. It is necessary for people to learn about fallout, about nuclear radiation about the effects of nuclear radiation on people, animals, plants, food, water: The things that are immutably linked to life. In a larger sense, this is a matter of getting up to date which is essential to good citizenship in any circumstance.

The peaceful applications of nuclear energy and the use of radioactive isotopes will grow with the passage of time. An informed public must be ready to express its opinions on the new proposals.

In the open literature there is a wealth of information on effects. The news media are making a regular contribution. The record of these hearings will add to the store.

Nevertheless, more public information and education will be required until we begin to reach the point where surveys show that Americans know as much about nuclear effects as they do about such familiar natural phenomena as rain, wind, floods, and electrical storms and the rather complex and sometimes hazardous equipment we use every day.

So then first we must add to and reinforce the foundations of public knowledge on which will rest our survival and recovery actions.

Second, we must teach people what to do to keep from being killed or injured by these effects in time of war. Actually this goes hand in hand with public education so that a man learns of the hazard and countermeasures essentially at the same time.

Third, we must be ready to back up and support these people with technological developments which will improve the effectiveness of their defensive preparation.

This then is the defensive pattern:

(1) Tell the people what they may be up against.

(2) Tell them what actions are to be taken before, during and after an attack.

(3) Support their efforts with new information, new tools and devices and new techniques.

We are all bound up in this together. People as individuals, as families, as heads of corporations, as governmental leaders from the smallest community on up. We cannot merely give this assignment broadly to our citizens and to their civil defense directors and walk off and forget about it.

As with any job the people doing the work are going to need general support, outright assistance with difficult parts, and the stimulus that comes with knowing that someone else is interested and ready to pitch in.

If we are to accomplish anything there will have to be a certain amount of initiative all around. We must surely progress further beyond the talking and planning stages, thereby setting a good example for those who look to us for guidance.

The policy of providing fallout shelter in new Government construction is an example of a practice which may be observed and copied.

It has been widely stated, and it needs to be said many times more, that for a man to be able to guarantee a high degree of protection for his family he must have a fallout shelter. This can be as elaborate as he likes and can afford. It can also be skimpy if he prefers to gamble with lives. But if heavy fallout is deposited in an area, the best use of the best available shielding against the radiation is an absolute must if the inhabitants are to avoid unnecessary radiation exposure, illness and death.

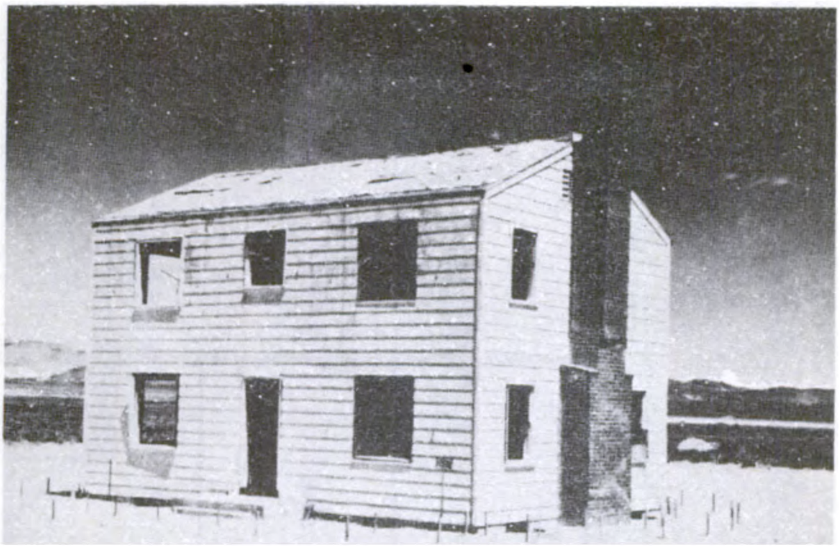
While we ordinarily speak of this shielding as a shelter, and while we think that people are well advised to provide themselves with a suitable shelter, it remains a fact that many homes and buildings provide a life-saving amount of shielding in their basements as they stand. It is a matter of learning where to go for the best protection.

In May 1958 in Operation Plumbob we conducted a study at the Nevada Test Site to improve our knowledge of the shielding, and thus the protection, which you might find in typical residences.

I will say we, the AEC, OCDM and all of us working together. But the AEC takes a real interest in this study.

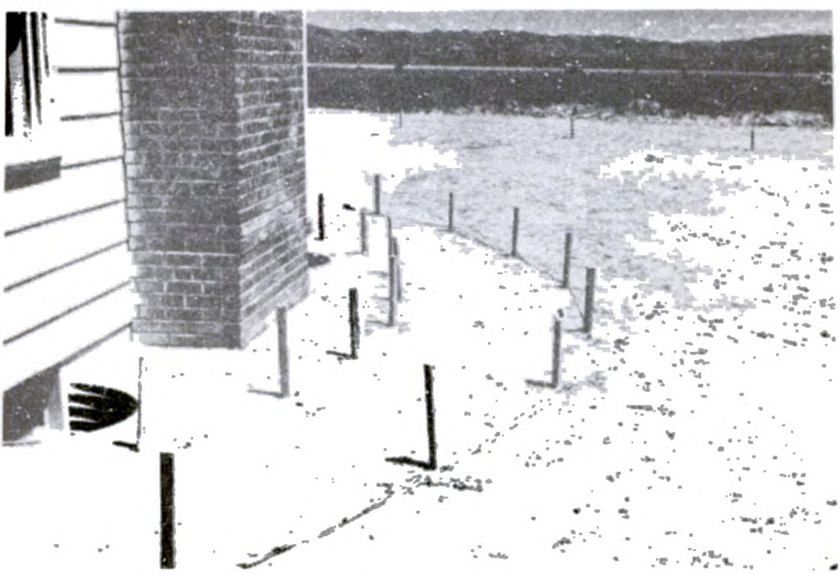
We used about 400 small radioactive cobalt sources encased in a plastic hose and arrayed about and over the structures to simulate the radiation field of fallout. We learned of the great possibilities of this technique and we learned some interesting things about the shielding in typical residences. (See charts 1 and 2.)

CHART 1



Two-story wood-frame house with basement showing radial arrangement of distributed sources to simulate fallout

CHART 2



Radial arrangement of distributed sources in plastic hose

CHART 3

SHIELDING FACTORS OF TYPICAL HOMES

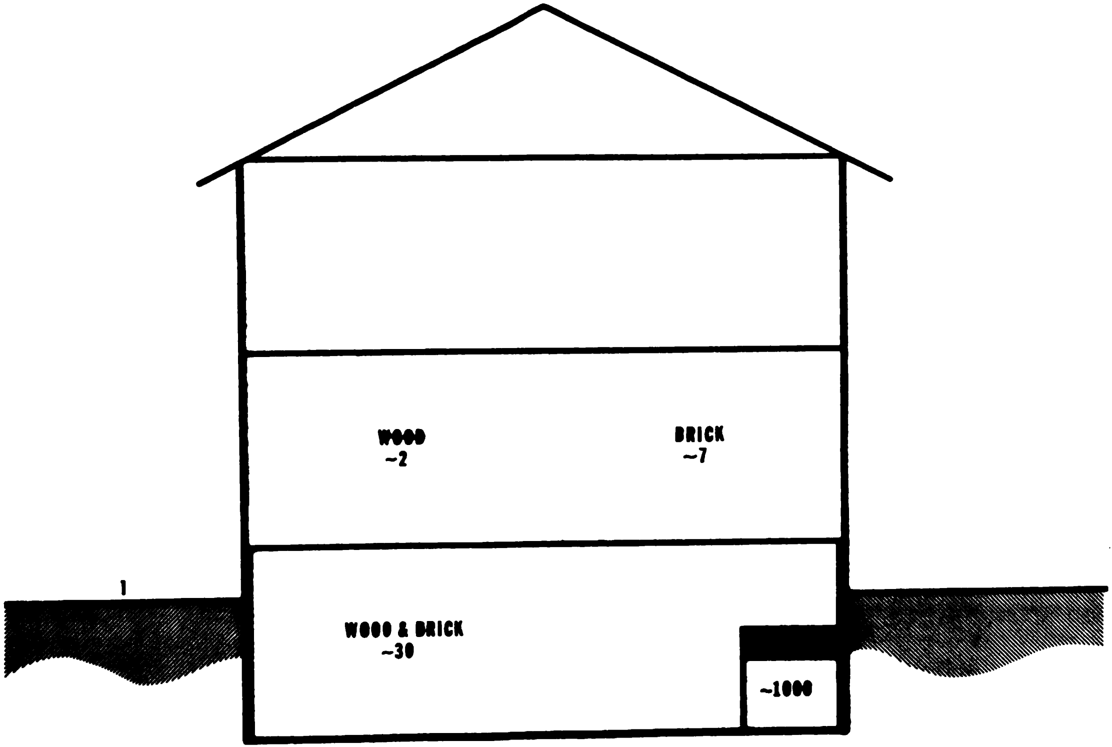
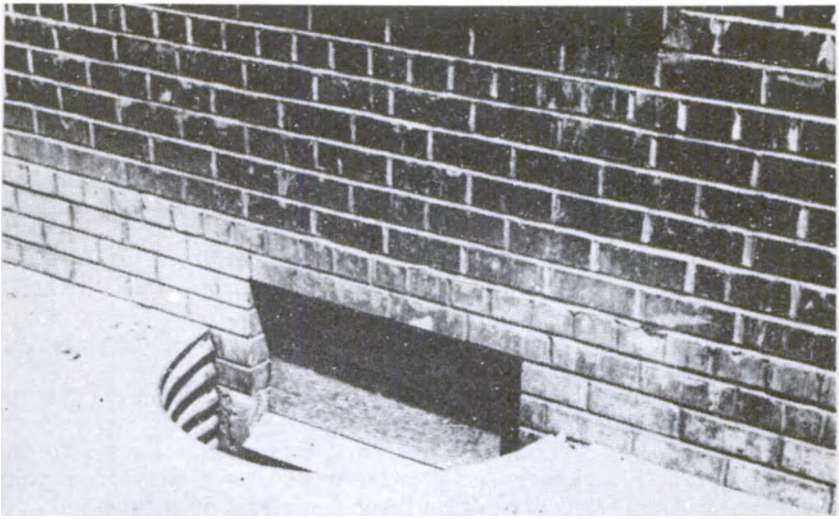
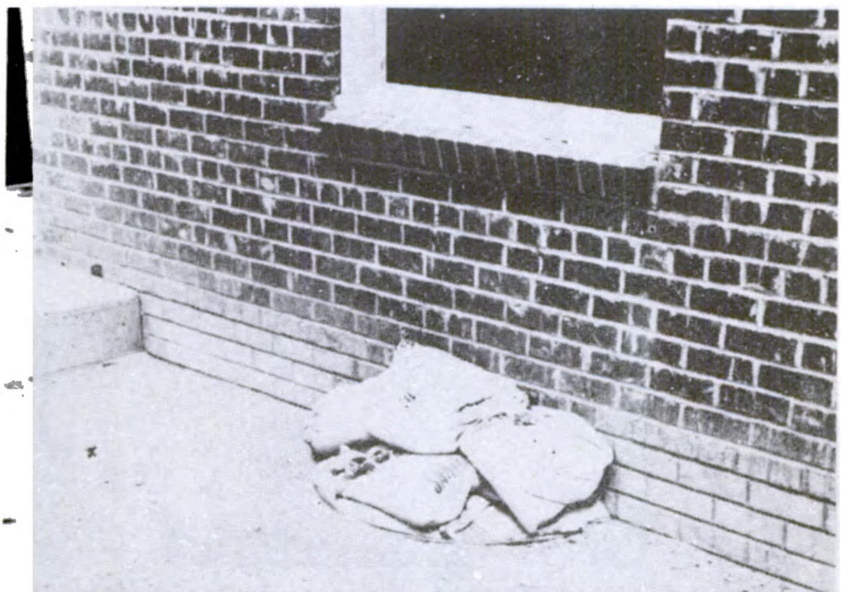


CHART 4



Cellar window, two-story brick house

CHART 5



Cellar window, two-story brick house, sandbagged

For example, it proved out that the most effective shielding material is that which is in the direct line of radiation.

On the first floor of a two-story wood building the average radiation was about one-half of that outside. On the first floor of a two-story brick building the average was about one-seventh. (See chart 3.)

A good many basements have windows and other openings which let the radiation in. By closing the openings with dense material like bricks or sandbags, the radiation level in the basement is reduced by a significant amount. (See charts 4 and 5.)

Kitchen and bathroom fixtures, bookcases, furniture, and closets cast shadows which give additional radiation protection. That is, these shadows are shadows of the fallout radiation.

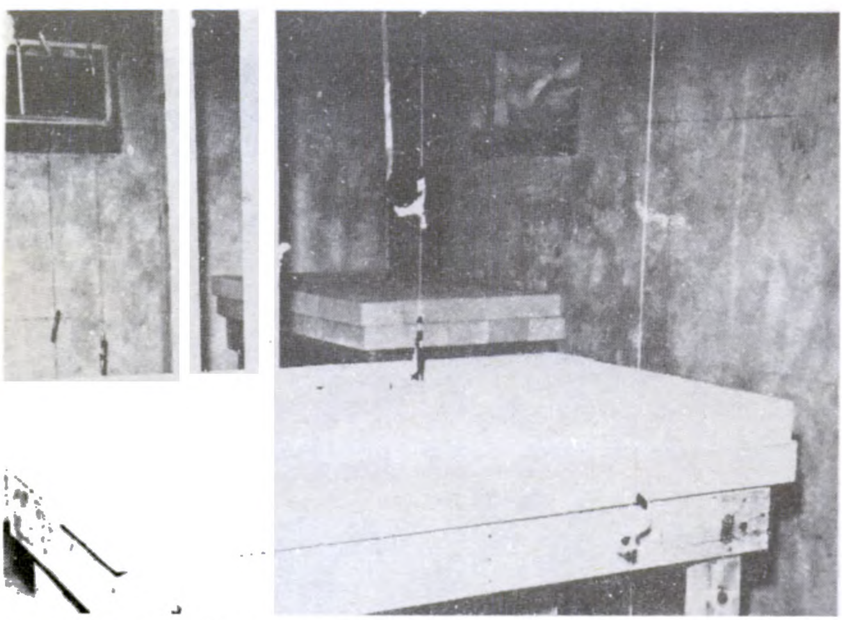
The location of the shelter area to take advantage of the shielding makes for a safer shelter.

Dose rates behind masonry chimneys and inside fireplaces are appreciably decreased.

The contribution of fallout on roofs of two-story houses to the dose rate on the first floor is less by a factor of 10 as you see from your second chart, than the contribution from the fallout on the ground outside the house.

In the Nevada experiments a shelter was improvised of a heavy table placed in the corner of a basement and covered with 7½ inches of solid concrete blocks. (See chart 6.)

CHART 6



Seven and one-half-inch concrete over table to provide improvised shelter in corner of basement and arrangement of intergrating dosimeters to measure radiation

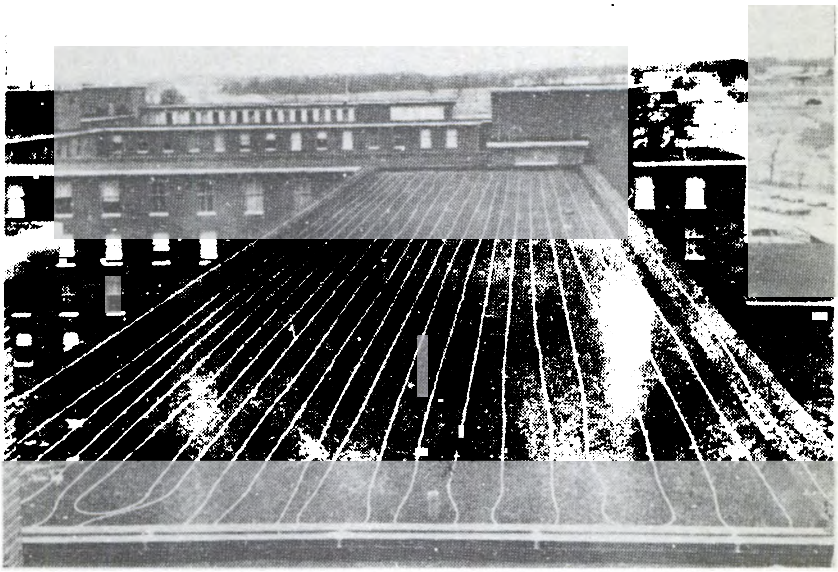
This is shown in the panel on the easel now. The radiation in this shelter was reduced by a factor of 200 to 100. This is getting to be very good protection.

A very simple device, a table covered with concrete blocks in a basement. We have summarized our study on the shielding from buildings in a booklet. We would suggest that you refer to it in the record, Mr. Chairman. It is available for general distribution.

Chairman HOLIFIELD. It will be accepted.

Mr. LIBBY. We have used a variation of this fallout simulation technique, that is the plastic tube with the cobalt 60 source being moved around inside of it, to make a survey of the shielding factor for our AEC headquarters building at Germantown. Now we have more to do in this line but I think I should tell you that these data are now ready for practical applications by the architects, engineers, and builders who design and construct our homes and other buildings (chart 7).

CHART 7



Arrangement of plastic hose to measure roof construction exposed to 200 curie moving radiation source

We think that we know enough to say that new building construction can have fallout protection built into it, and at costs which are not very large, and may in some instances be zero.

From this information I draw the conclusion that millions of people would be saved from injury and death if they made good use of what was already available to them. Good fallout shelters such as those which the Office of Civil and Defense Mobilization is publishing, will save millions more.

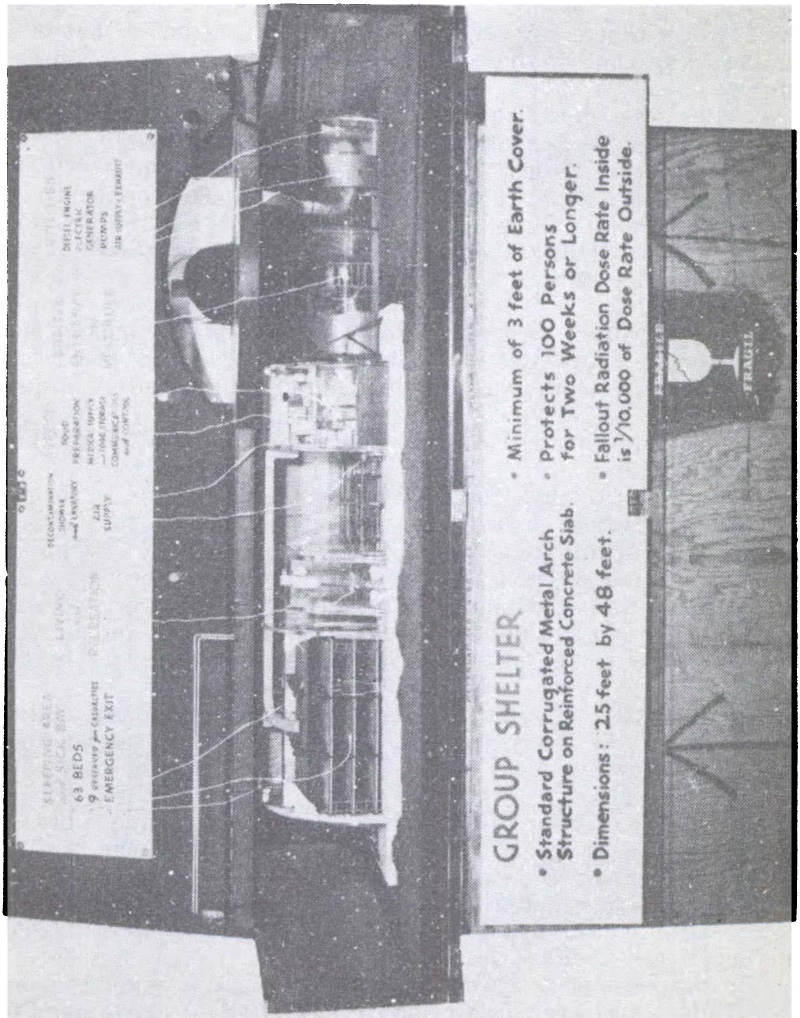
All the people in the Nation won't be close to their home shelters at the time of an attack or when the fallout arrives. So it is important that some thought be given to the protection of the man on the job.

We have good protection against fallout in our building at Germantown, for example.

Because that was built with an eye to defense. We have also been doing some work on an AEC group shelter which will furnish excellent protection and at the same time be relatively economical to build. When we have finished our work on this it is expected that we will find that the shelter is adaptable to meet our needs throughout the AEC.

We have a model here which I would like Mr. Corsbie to demonstrate to you. This group shelter which you see as a model is essentially the same as shown in the film you saw yesterday (chart 8).

CHART 8


GROUP SHELTER
• Standard Corrugated Metal Arch Structure on Reinforced Concrete Slab.
• Dimensions: 25 feet by 48 feet.
• Minimum of 3 feet of Earth Cover.
• Protects 100 Persons for Two Weeks or Longer.
• Fallout Radiation Dose Rate Inside is 1/10,000 of Dose Rate Outside.
63 BEDS
EMERGENCY EXIT
FOOD PREPARATION
DIESEL ENGINE
ELECTRIC GENERATOR
PUMPS
FRAGILE

This was tested as a radiological shelter at the Nevada test site in Operation Plumbbob in 1957. It was located 1 mile from a detonation of about 20 kilotons, that is equivalent power of 20 kilotons, and was occupied by Mr. Corsbie and other people working on the project at the time of the explosion.

Three times, three detonations. Now in 2 of these detonations the fallout patterns close to 100 r. per hour fell right across the shelter as we had hoped it would. The blast pressure was 4 pounds per square inch. Now that is important because it is to be noted that in Hiroshima 35 percent of the casualties occurred at lower pressures than this.

Earlier tests demonstrated that the basic shelter would provide protection against as much as 25 pounds per square inch.

The radiation reduction factors was 10,000 or more, so it would seem that this shelter, that one could have a lot of confidence in this particular design. Now it may be described as a buried or mounted 25 by 48 foot metal arc structure as shown by the panel in the easel and in the model cutaway. It will accommodate 100 people for 2 weeks we hope.

I say we "hope" because we don't know as much about prolonged occupancy of a shelter as we do about providing fallout protection.

Engineering work on modifications to the shelter is nearing completion.

Mr. Corsbie's model here shows in considerable detail the kind of thing that is underway.

It is planned to make these changes to the shelter now in the ground at Nevada test site during the summer and then go to work on the matter of learning something about the problems of living in the shelter. I think we will all feel uncertain and uneasy about telling people to be prepared to stay in a shelter for a week or two until we know about what this means in terms of human habits and adaptation.

These experts are in a way like those described by Mr. Strope yesterday.

Representative HOSMER. Dr. Libby, has there been any analysis of the material the Navy acquired during its studies of confinement prior to the development of the Atomic submarine, the psychological matters run into?

Dr. LIBBY. Yes, but I think the problem is rather unique here. The geometry, the way you sleep, the freedom of movement is different from a submarine to a certain extent and we ought to really check it out. We like this shelter. We think it is practical, it is economic and it is useful, but this is a big unknown. Maybe people just can't stay in there 2 weeks, but we think they can.

During the tests of the shelter in 1957, we had personnel from various AEC operations offices come to the test site to participate in the experiment and to get some firsthand experience.

Thought is being given to similar participation in the human engineering experiments. In this manner we can inform the staffs in the field of the practical aspects of the program.

Also working with AEC and contractor personnel in the field, we shall start using at Oak Ridge late in June a radiological survey vehicle, commonly called a fallout truck.

This vehicle will be equipped with instruments and radioactive sources which can be moved about to simulate fallout radiation.

The work at Oak Ridge will determine the fallout shelter characteristics of employee homes, provide experimental information on the best combination of sources and instruments for the purpose, and proof test operational procedures for conducting the surveys quickly, accurately, and safely.

These radiocobalt sources that we use in the plastic tube are fairly strong ones and we have to be quite sure that they are used without hazard.

With equipment like this we can tell a man how much protection his house provides and point toward steps which will improve the protection for his family and himself.

A man must not only know where to get staisfactory protection, he must also know when, how long to stay in the shelter. He needs some means for determining when it is safe to emerge and how long he can remain exposed. How can he know if it's better to stay hungry for a day than to go outside for an hour or so to forage for food? How can he tell if he has any fallout problem in the first place?

As you saw from the earlier presentations, the local variations, the hot spots, and the cold spots are very sizable, and though the general pattern may be downwind to your home, he has to ask how can he be sure that he has a fallout problem.

I am sure that the committee has been informed on the civil defense radiological defense program and knows of the progress being made in the training of radiological defense personnel.

From data produced by the local radiological defense units, the community leaders can advise the populace by radio broadcasts. Each family should have as a part of its shelter also equipment including a portable radio so that it can get the information from official broadcast sources.

The new transistorized radios, several of which are displayed here on the table before you, are especially good for this purpose. The reason is the batteries last longer.

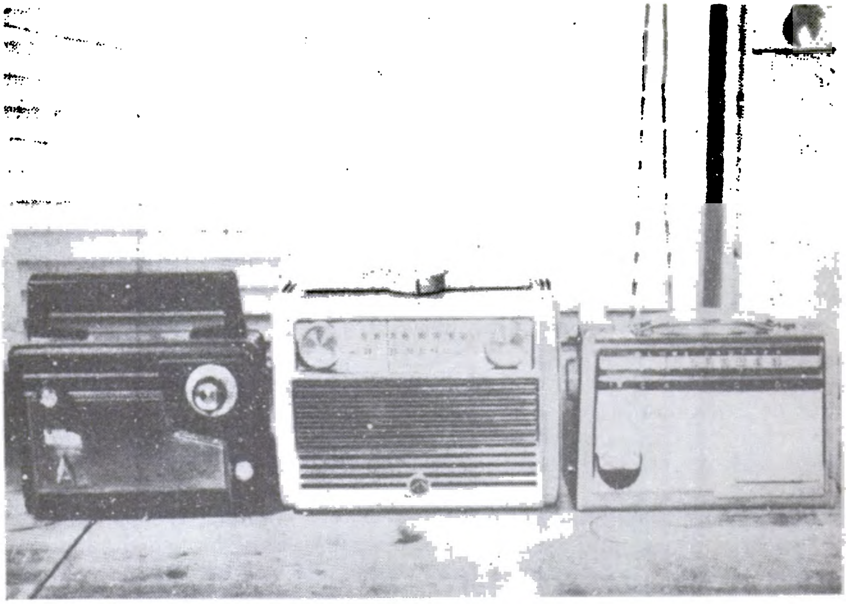
Once the radiation levels decay to the point where radiological defense personnel can move around the locality, we can expect that they will get in touch with the people bringing information on the radiation levels in the immediate vicinity. These sources of information for the people are good but we need more.

Suppose you are on a farm. No one is going to come out and measure your farmyard, and you won't know from the civil defense sources.

Governor Hoegh has joined with me in a statement released on May 15 ,1959, which says that we believe in the concept of providing people with instruments so that they may be able to measure the radiation levels themselves; so that they may be able to tell when fallout arrives, so that they may have an up-to-the-minute basis for decisions, and so that they may not be handicapped by events which may preclude the radiological defense personnel from carrying out their assigned missions.

I have with me today some examples of what we have called citizens' instruments. These represent a number of approaches to the problem. They represent the efforts of people in the Federal Government and people in the electronics industry (chart 9).

CHART 9



Combination radio-radiation instruments, "citizens instruments," (left) developed by AEC, Radiation Instruments Branch; (center) Tracerlab modification of commercial marine portable to include "Banshee" radiation warning element; (right) manufactured by RCA to AEC order

The prototype of this first combination radio-radiation detector was developed by Mr. Dick Johnston and people in our Radiation Instrument Branch, the Division of Biology and Medicine, and 25 have now been manufactured for us by RCA under contract.

Mr. Johnston is holding one of them up there now and you will see the source activates the needle. The needle is moved over.

I don't know whether you can see it from the rostrum, but you will see if you're close enough that it has moved.

Now this needle on this meter when it hits the red area is indicating a dose rate of something above 1 roentgen per hour. As you will recall from the earlier testimony, this is the kind of dose rate which becomes worrisome.

Representative HOSMER. How high will that register?

Dr. LIBBY. The top part of that is 10 roentgens per hour. These can be set, though, to various levels. They differ; the various types of citizens instruments we have here differ in the ease with which you can set them to various levels.

The one Mr. Johnston showed has a Geiger counter inside of it and is more sensitive than some of the other ones we are going to show.

What he did was take a standard commercial transistorized radio and to it he added a Geiger counter and an instrument dial so you can read.

With this instrument the family can keep in touch with the authorities by listening to the conelrad or other radio broadcasts from

stations in their vicinity. Using the Geiger counter the family can measure the radiation hazard in the environment.

And may I say in the food they intend to eat, because if the food were hazardously radioactive it would activate these counters, the Geiger counters.

We have another instrument here which was developed from some results obtained in the Naval Research Laboratory by the Tracerlab Co. This instrument is called the Banshee because it sounds an audible warning of fallout radiation (charts 10 and 11).

CHART 10

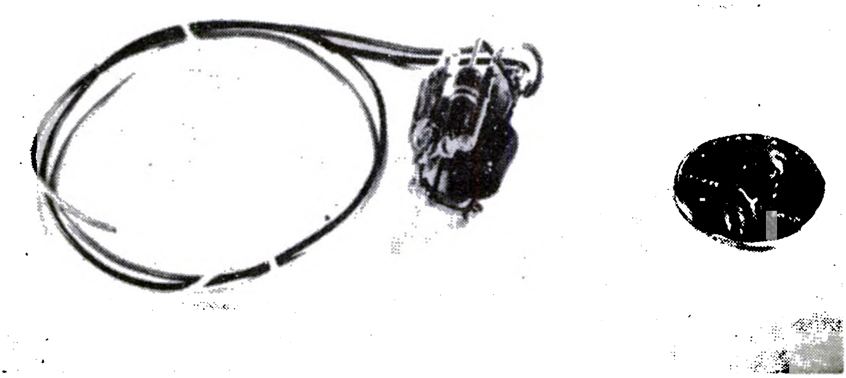
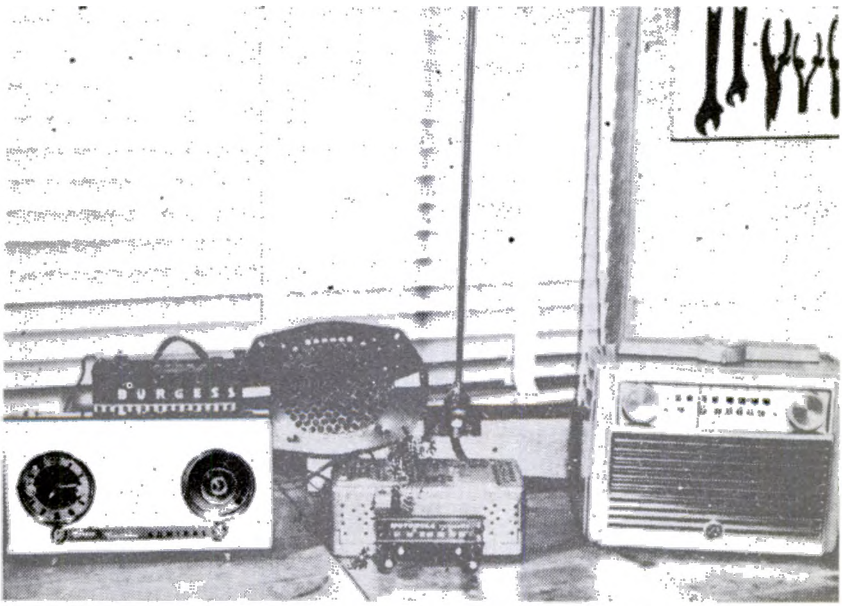


CHART 11



"Citizens instruments"—portable radios which have been modified by addition of Tracerlab's "Banshee" radiation warning device: (Left) portable table model radio; (center) automobile radio; (right) marine radio

I am not sure the Tracerlab did not rediscover this, but there was an earlier priority in the Naval Research Laboratory on the basic idea of this instrument, which is to use a cadmium sulfide crystal which becomes conductive in the presence of radiation to turn on an oscillator circuit to make a squeal or a howl which you will hear in a minute.

The sound comes out through the speaker of the radio. Go ahead, Mr. Johnston.

As you have seen, this sound is sufficiently loud to wake anyone who might be sleeping at the time the fallout commences to arrive.

In a similar manner it would attract the attention of members of the family who might be in another room or outside.

The Banshee dectector warning unit can be attached to a wide variety of radios, as you can see from the demonstration models we have here.

Would you mind pointing those out, Mr. Johnston, the various models to which attachment has been made?

Mr. JOHNSTON. This is the basic circuit diagram on the Banshee attachment. This is an automobile radio when it is incorporated. There are several models of AC-operated clock radios here as you can see.

This is a portable marine type radio to which the circuit has been added. The leather encased clock radio is a portable transistorized radio. The little yellow one beside it is another portable transistorized radio and this is also one to which the Banshee has been attached.

Dr. LIBBY. Now we have other models as well.

Chairman HOLIFIELD. Your thought is that these would have to be left turned on overnight?

Dr. LIBBY. These must be turned on at the time of the test for radiation and also they would presumably have a button. You would not want them to be necessarily activated all the time or you might. This is something that would have to be decided.

It would cost very little to make this button. But I imagine you would want to have a switch so you could turn it off.

Chairman HOLIFIELD. This would not indicate degrees.

Dr. LIBBY. Oh, yes, the sound has some correlation. When we tested our building, we put one of these Banshees on my desk and laid the plastic tube across the roof of the building. The Commissioners' offices are on the top floor. Next a tape recorder was placed in my office. It was too dangerous in the room to stay in there, but the tape recorder could stay in there. Then we played it back, and you could hear this source coming. It would go behind a post. You can hear it fall down and then as the source came up and went back and forth across the building you could hear it. So you would have a rough kind of correlation but it is not as good as the meter by any means, and is a qualitative warning. Now these are set, so that if they start howling, you had better seek some shelter.

It is set at the 1 to 10 roentgen per hour level.

Chairman HOLIFIELD. Those will be available commercially I suppose, and if so at approximately what cost?

Dr. LIBBY. Our game, Mr. Holifield, has been to get a free ride on the large number of transistor radios that are being sold now.

As I pointed out a moment ago, the transistor radio is ideal as the citizen's radio for keeping in touch with the civil defense authorities. It is light and it has batteries that last a long time. It is a very practical thing. It would prove to be very popular. A great number of them are being sold. It is our purpose and intent, since we have been working on this for the last 18 months, to get a free ride, essentially a free ride. That is to have the attachment, whether it be the Banshee or whether it be the meter or one of the other devices which are shown here, whatever is attached, have it inexpensive enough so that it adds only a small amount to the cost of the radio.

Representative HOSMER. You could be sure to get one of those in everybody's home if you made it also to cut out the loud and noisy commercials.

Dr. LIBBY. Thus a man in buying a radio for pleasure, would also be buying some protection for himself and his family at what we hope is a nominal additional cost.

Now I have a series of, a set of papers here on progress reports on the cost estimates from various companies. We have asked the RCA company and Westinghouse and Motorola and one or two others to look at this, particularly the Banshee but also to consider some of these others, but we are sort of concentrating on the Banshee at this time in order to get a definite figure, and see whether we can get the cost under $10. That is an additional $10 added to the price.

Governor Hoegh seems to think and most people seem to think that if we can get it under $10 it will go.

If it is much over that, it might be difficult to make it work, so we are trying to see whether we can get these made for an additional cost of something like $10.

I am in no position today to assure you that this can be done.

Our present reports indicate that it is possible it can be done. It is even probable, but we have not an assurance. It may be something like $12.

Chairman HOLIFIELD. Was this developed by the AEC?

Dr. LIBBY. We have taken a great deal of interest in it, and I think we were one of the first groups to initiate it. But the electronics industry, and as I said the Naval Research Laboratory was working on this cadmium sulphide quite a while ago.

Chairman HOLIFIELD. In other words this is not a proprietary act.

Dr. LIBBY. No, it is not, and our problem is to get it manufactured cheaply enough, and there is no problem of patent royalties or anything like that involved in it.

As I said, there are other combinations which have been developed, and I am sure that we will see more in the future. I hope the demonstration and the explanation of these first beginning models may lead engineers to invent better ones.

We hope they will all combine a capability to hear radio announcements of critical importance to a family and to obtain equally important critical information on the radiation hazard around the house.

I regret that I can't tell you, you can go downtown in Washington or in other cities and towns across the Nation and buy one of these in an appliance store. These models represent an idea for a simple, relatively inexpensive way to keep from getting a dose of

fallout radiation which would make you sick or kill you without your knowing you were exposed.

Just think of it, you have not seen any fallout and you live out in the country, and you may quite unknowingly get a lethal dose or a near lethal dose. There is argument as to whether you can get a lethal dose with an invisible fallout.

To make this idea successful, we need engineering attention on the technical details, and above all, the interest and participation of the Nation's electronic industry.

I should not want anyone to get the idea that we think these instruments will do away with the requirements for the regular civil defense radiological instruments for the radiological defense personnel who are being trained and organized. There will always be a need for a well-trained, well-equipped monitors and for people to direct their activities.

In the postattack period an early action would be the training and equipping of new replacements to assist with recovery operations.

It has been our practice to think principally in terms of survival during the attack period and a short time afterward. We must remember that a war in which large numbers of nuclear weapons are detonated will present us not only with widespread destruction but also with widespread, long-lasting radioactive contamination.

Ultimately recovery will take years. Those who survive will learn that bringing about recovery may be more difficult than living through the attack.

It behooves us then to put some of our best minds to work on plans for the actions to be taken during the years following the cessation of hostilities.

The ultimate victory in the military phase of a war may depend in only the slightest and remotest way on the survival of any 1 family or any 10,000 families.

It may not depend in any way on the fate of a single family. But in the recovery period the Nation will depend greatly on the energy, wisdom, ingenuity and courage of every surviving citizen.

We must therefore be sure that our fellow Americans know how to survive, encourage them, help them.

In this manner they and we shall stand ready for the test.

Chairman HOLIFIELD. Thank you, Dr. Libby.

Are there questions from the members?

Senator Hickenlooper?

Senator HICKENLOOPER. I am sorry I wasn't here when Dr. Libby began his testimony, but I am aware that this probably is one of the last if not the last time that Dr. Libby will appear before this committee in his official capacity as a member of the Commission, and I want to say to you, Dr. Libby, that you have contributed a degree of unusual skill and experience to the Atomic Energy Commission that has never been excelled. I don't think it ever will be excelled.

Dr. LIBBY. Thank you, Senator.

Senator HICKENLOOPER. You came to the Commission with the background of tremendous accomplishment in your own right in science, tremendous experience. You have brought to the administration of your duties in the Commission a very practical and a very hardheaded approach to some of the most difficult problems that we have ever faced as a Nation.

I can only say that I don't believe I can gild the lily by anything I say except in my feeble way to express my appreciation of association with you and the great satisfaction that has come to me over the last 5 years or so to be able to get the benefit of your vast previous experience and the great satisfaction of being able to rely utterly upon your practical presentations, the honesty of your approach and all those things that go with the sincerity of the performance of a duty and obligation, and in fact the privilege which it is to serve one's government. I understand, I know that you are leaving the Commission of your own volition. I am personally extremely sorry to see you leave.

But by the same token as a man of science I can understand that if you get away from your test tubes and your pencils and your calculations of all those things in your profession for too long a time and your association with them, you may feel that you are going backward rather than forward, and I could understand your desire to get back to doing the things for which you are most eminently trained to carry on the studies which you have so highly successfully and uniquely brought to the benefit of humanity and our country.

While I am very sorry indeed to see you go, I can only repeat again that we all have benefited immeasurably from your contributions, from the ability to rely upon your sound calculated and measured experienced judgment in this matter, and I know others have expressed themselves similarly, but I want to add my personal very best wishes to you and to your satisfaction in the future in the work that you will carry on in the way that you are best fitted to do.

I know that we on the committee and our Government have full access to any assistance or contribution which you can make in the public interest from time to time regardless of where you may be or what your occupation is, and I wish you God speed.

Dr. LIBBY. Thank you, Senator Hickenlooper, for your kind words. And I certainly want to help in any way I can at any time.

Chairman HOLIFIELD. Thank you very much, Dr. Libby, for your testimony today. As you go you know the good wishes of the full committee go with you.

Chairman HOLIFIELD. In reviewing the broad scope of subjects which, by necessity, has to be included in these hearings so the American people can be furnished a technically correct and academic report on the biological environmental effects of nuclear war, the committee feels the following principles have been established on the basis of testimony before our committee.

One, approximately 25 percent of the population or 50 million would die as a result of the hypothetical attack considered during the hearings.

Two, the Nation could recover from such an attack. However, tremendous effort and energy as well as resources must be expended in preparation for such a recovery. The Chair notes that such effort and such energy has not been expended and such planning has not taken place.

Three, protection measures of various degrees can be provided and are technically feasible, the adoption of which could reduce the estimated casualties considerably.

This is in no way to be considered as an advocacy of such a war of course. It is not said with any blitheness on the part of the chairman.

It is said as a matter of record of the hearings. The panel has been called together to consider the implications these conclusions could have upon the strategic position of the United States, particularly in the nonmilitary aspects of deterrence. Will the following gentlemen please step forward to the panel: Mr. Corsbie, Dr. Tompkins, Mr. Kahn and Mr. Strope?

Dr. Libby is already at the table. Will you gentlemen join Dr. Libby and we will proceed with the panel?

Gentlemen, when we think of the defense of the United States, we ordinarily think of military defense. Today we have had testimony on a possible passive type of defense, nonmilitary defense, but a factor which is ordinarily described as civilian defense.

What are the reasons for nonmilitary defense, and is nonmilitary defense necessary to support military defense in a war of this nature?

Dr. TOMPKINS. Mr. Chairman, I believe it would be well to establish for the record the fact that all of the gentlemen at the table are here strictly in their roles as individual citizens. That the subjects under discussion from an authoritative governmental point of view requires an entirely different group, and we in no way can represent anyone but our own views and opinions.

I believe it is important also, I would like to propose to the committee, that our most profitable contribution to these hearings would be to consider primarily the concepts underlying the relations rather than any arguments about a particular program that may be suggested to implement it.

If I may introduce just a little background, in listening to the testimony of the last 2 days I believe we have looked at three parts of the nonmilitary defense.

Dr. Libby's presentation has been an excellent exposition of those things which the individual citizen can do for himself.

As soon as one says this, it is important to realize that these things make sense only within the context of the society in which the citizen must function during these periods.

On the other hand, Mr. Strope gave a presentation of a type of protection that is more suitable for larger groups and theretofore has more implications with respect to formalized Government action. If I have read Mr. Kahn's message correctly this morning, he has stepped upward to a completely broader plane and has asked or made the very basic notation that at the present time we depend on avoiding war, and if I read him correctly, you feel that with the programs currently proposed by the country we are not prepared to fight and win if this becomes necessary?

PANEL DISCUSSION ON STRATEGIC IMPLICATIONS

Participants: Dr. Willard F. Libby, Commissioner, USAEC; Mr. Robert Corsbie, Director, civil effects test operations, AEC; Dr. Paul Tompkins, NRDL; Mr. Herman Kahn; Mr. W. E. Strope, NRDL.

Mr. KAHN. A little too quick, Dr. Tompkins, though very good. I think we depend a great deal too much on deterrence, without analyzing the notion carefully, without, for example, asking ourselves such simple questions as, "Are we trying to deter direct attacks on the United States, or are we trying to deter attacks on Europe?" Require-

ments for these are quite different. What is satifactory for one may not be satisfactory for the other. Second, I don't want to give the implication that we think that civil defense plays a role in military affairs in the classical sense of the word, by backing up the Armed Forces, supplying them with men, materials, and morale. In some real sense, civilians and cities are not much of a military target—this is oversimplified but you have to oversimplify.

Cities do contain such military assets as communications, municipal airports, off-duty personnel, and so forth, but I would doubt that all of the military assets in all of our cities are equivalent in military capability to a couple of wings of B–52's. You don't protect civilians today because they fight wars. You protect civilians because it is the job of the military to do that and not the job of the civilians to protect the military forces.

It is very important to realize this. Sometimes people forget it.

Second, you protect civilians because unless you can do this you are vulnerable to blackmail, either before the attack, during the attack, or after the attack.

Representative HOSMER. How do you use the term "blackmail," Mr. Kahn?

Mr. KAHN. I use the word in the customary sense, where the other side uses threats to influence your behavior and maybe even to make you pay off.

We discussed earlier the possibility that if we cannot accept Russian retaliatory blows, and if it is clear to us, or the Russians, or the Europeans that we cannot accept them, then we may be in a very precarious position.

That is, you have to persuade all three simultaneously. Then we asked ourselves what do we mean by accepting a retaliatory blow, and we noticed the rather different views Europeans and Americans seem to have of the credibility of our initiating actions leading to that possibility. I have no information as to what the Russians would think, none at all.

This is preattack blackmail. The other kind of blackmail is a little too technical to discuss now but it is discussed in papers, as the so-called postattack blackmail. He can influence your behavior after the war is started.

Dr. LIBBY. Of course, in World War II, I think we learned that the whole Nation has to fight the war. That is, industry was an integral part of the effort, and certainly in that sense civil defense is part of it.

It may be even more directly a part of the effort than the heavy industry was in World War II.

But it seems to me not too extreme a position that civil defense is pretty closely related to our defense posture.

Mr. KAHN. I would like to make a partial exception to Dr. Libby's remark. Many people object to air and civil defense, not because they underestimate the problem, but because they overestimate it. They thing there is nothing significant that can be done to alleviate the consequences of a war.

For example, if you examine most air defense studies done in the United States, say until about 2 years ago, it almost always turns out that one of the objectives of the study was to defend the war mobilization base.

Now you can't do that job, therefore if you believe that this is the objective you come up with the position why spend money on air defense or civil defense? There is, however, another question which is also important: "How does the country look 5 or 10 years after the war as a function of the prewar preparation?" For this question one does not ask, "Can we produce jet engines in the first year of the war?"

Now the first task cannot be done, but the second can. Therefore you are actually hurting yourself if you try to overstate the importance of civil and air defense by saying that we need the output of these factories to fight the war because you are then setting up an infeasible objective which automatically leads to apathy.

The problem is, "Can you do the much easier job?"

Dr. LIBBY. Yes; I think that is a very reasonable point. There is a psychology of action that is necessary rather than a psychology or an attitude of hypothetical and theoretical consideration.

If we could get citizens interested in a few things like basement shelters so that people had the feeling that they were doing something to improve their position, their attitude toward the civil defense operation might change, so that one of some hope might take the place of one of pretty general despair and hopelessness.

Mr. KAHN. May I add something to that?

If you expect people to have faith in these moderate preparations you have a right to ask that the Goverment have some faith in them too.

Chairman HOLIFIELD. Will you speak a little louder, please?

Mr. KAHN. If one expects the average American citizen to have faith in modest preparation like simple fallout shelters, 2-week food supplies, and so forth, one also has the right to ask the Government to have faith in these programs.

Conversely, if the Government shows that it does not believe that these modest measures will be effective, then how can we expect the citizens to believe in them?

The Government has obviously shown it does not believe in moderate measures because it supports them in a rather modest fashion to understate it.

Now we have looked at this problem, we have asked ouselves what is the minimum task you can ask civil defense to do, and we come up with two.

The first one would be to prepare what I called the B country, that is, the rural areas, small towns, and so forth, to survive and recuperate from a war in which the A country, the largest 50 to 100 cities were destroyed.

For at least the near future this is a relatively simple and feasible task and we don't think it costs very much to make these preparations. The second task that we think should be done is to have the capability to take the people of the A country and put them in places of protection in the B country on say 24 hours' notice. I am using the dirty word "evacuation." It is not wishful thinking to think of 24-hour evacuation capabilities as being useful.

It has nothing to do with the belief that we have a secret agent in Moscow to give us intelligence. It simply depends on the following: That as far as the Russians and the Europeans are concerned, they

will have a quite different attitude toward the resolution of the United States if they think that the United States can put its people in a place of protection given 24 to 48 hours' notice, than if they feel that even given a month's notice there is nothing we can do.

In other words, imagine yourself going into a Munich-type conference where the Russians had evacuated their cities and you had not. They may even have done it slowly, say over a period of a week, and now you have to bargain with them, and they are evacuated and you are not. You are going to have some very tough bargaining to do.

Chairman HOLIFIELD. Any comment, Mr. Strope, Mr. Corsbie?

Mr. STROPE. No. This was a point that I wished to be brought out and it has been brought out somewhat already. The concept of a country A and a country B is very useful. It is useful in civil defense because the problems of defense are completely different in the two countries.

Protecting country A is a very difficult problem. Protecting country B is a very reasonable problem. I think the question which is most important right at the moment is: Suppose we have made country B impregnable in the face of a Russian thermonuclaer threat. How does this change or how does this affect our general posture in deterring a war?

I think that Herman has considered this at quite considerable length.

Chairman HOLIFIELD. Mr. Corsbie?

Mr. CORSBIE. I think in preparing our defenses, that we somehow or other must put the information which we now have into engineers' and architects' offices so that they can provide routinely the sort of protection which we know is needed. Dr. Libby mentioned in his remarks that this might cost very little.

Now for too long we have known that some materials are functionally equal to other materials and competitive in price, but from the point of view of providing protection against nuclear reactions are far superior. Also, we know it takes quite a while to make changes when one is affecting parts of our economy and ways of doing things.

For instance, we have known for a long time that hard smooth materials are much better in the face of fallout contamination than rough materials.

We have known for a long time that certain frailable, frangible building materials under blast conditions break into thousands of fragments, each one a potential casualty producer.

So we need to reorient our thinking somewhat to recognize that we are living in an atomic age, and if we never had to face a war—for instance, we should not expect to have lower radiation levels. So we need to recognize the materials that are useful to us, and we need also to recognize that changes in design of a thing as simple as a house can provide additional protection merely by leaving out basement windows.

We have forgotten that basement windows were put in houses years ago when our forefathers lighted the basement by daylight, but no one ever turns off a light today because the room has a window. So we could build a basement cheaper and probably ventilate it as efficiently without openings as with openings.

Also, if as simple a concept as the fact that protection against radiation is closely related, almost proportional, to unit-area density of material between the contaminated area and the safe area could be put in the drafting rooms, then the people who are experts in design and selection of materials, might start substituting say concrete floors in typical residences for wood floors. By such means you might have as good a basement shelter in a one-story wood rambler house as you now have in a two-story house.

Chairman HOLIFIELD. Mr. Durham?

Representative DURHAM. Referring to your statement in regard to this projected future, and of course you have made this study—you can prepare yourself to take so much destruction of human lives and human property.

We have to assess it on that basis and then come up with some kind of an answer as to whether or not we could take a loss of 40 million people and whether we could take a loss of 50 percent of all property, food, and everything else.

I would like to have the panel comment on that.

I think it would be very interesting in dealing with the approach as to what we may think of in the future. I believe you did approach it in the future, not presently.

Mr. KAHN. Yes.

Representative DURHAM. That is we are reaching the place here where we can't get enough money or we can't find enough funds unless we all do it individually in trying to portect ourselves, and there seems to be very little interest, with all the effort we have put out here and put out in the agency.

If the panel would care to comment on that I thought it was a very intriguing and interesting point in the future picture of wars that we may face in the next 30, 40, or 50 years.

Mr. KAHN. Or even less than that.

Representative DURHAM. Less than that.

Mr. KAHN. Right. The question of what you are willing to accept in the way of a retaliatory blow depends a great deal on the provocation.

In other words, the Russians have done things to us and maybe we have done things to them which 30 years ago would have meant war but today does not. The balance of terror is delicate but not that delicate. It is hard to overturn. However, if the Russians dropped a bomb on London just like that out of the blue, I think they would find bombs on Moscow, even if their retaliatory blow killed more than half of our country, simply because we would not even stop to think.

We would just react.

On the other hand, if we had made no preparation to accept a retaliatory blow and the Russians got us to a Munich-type conference say 5 or 10 years from now after they had us put into a very tense period and made us think about it and then relaxed us and then raised us again to a peak of tension and then relaxed us—just the way Hitler did, he gave us a model.

Representative DURHAM. I understand you think, of course, under that circumstance that they are going to try to come up with an answer as to how much they are willing to take before they ever drop that bomb?

Mr. KAHN. That is right. They can test you experimentally and find out gradually what you are willing to take, and they can probably do it reasonably safely.

They can't do it completely safely. They run some risks.

But there is another point to realize: It does not have to be down in black and white before our NATO relations get influenced. They can think just as well as we can, in some cases they can think better because they are closer to the gun.

In the past the Europeans have resolutely refused to look at this problems because it was too horrible. But it is getting closer and at some point you have to look even horror in the face. You are forced to. At that point when they start asking the question, "Will we give up New York for Paris, will we give up New York and Washington for London", you have to give them a story which sounds reasonable, at least to them if not to yourself.

You have to because they are going to ask for it. Now you may give them a story which sounds reasonable to a certain percent of the people but to others it won't. It then becomes a political issue, and the more you argue this thing the less credible it comes unless it has a modicum of rationality in it.

Representative DURHAM. With that kind of a plan what is the difference between that and a deterrence plan?

Mr. KAHN. What kind of a plan?

Representative DURHAM. A deterrence plan under which we are operating at the present time?

Mr. KAHN. Let me be very careful. It is in a sense the old massive retaliation that Secretary Dulles talked about in January 1954, but only in a quite different context. I do not believe that one should, even in the most indirect way, threaten massive retaliation for such incidents as Korea and Indochina.

These issues are just not big enough to justify world war III. In fact the less you talk about massive retaliation the better, up to the point where you get to really serious issues like all of Europe or even a piece of Europe, but where the principle involved is a really big issue. At that point you have two choices. You can try to defend it with limited war forces on the ground, or you can try to defend it by Strategic Air Command.

For the last 4 or 5 years the Strategic Air Command has been a very credible defense of Europe. I personally think this defense will still be credible for some period in the future, though some critics have cast doubt on its credibility. In any case, our resolve to use SAC is rapidly diminishing in credibility. Furthermore, you have to take account of a peculiar human reaction which tends to anticipate trends and acts as if the future is already here.

In other words, the Russians test a missile so some Europeans and Americans act as if they have 500 missiles in existence. This is a human reaction, to look at a trend and anticipate it arrival prematurely.

Representative DURHAM. We are getting over the base, Mr. Chairman.

Mr. KAHN. My apologies, the only point I'm trying to make is that Type II Deterrence is a form of massive retaliation if you will, but on an issue which may be worth it. It has been credible in the past. It

is credible now. It may not be credible in the future for just such reasons as given in the testimony we have had in the last 4 days.

Dr. LIBBY. I think, Mr. Chairman, that by pursuing the program of hope and of citizen's individual action program, we may develop a knowledge of the realities which will make people better able to assess the factors Dr. Kahn has brought out. So I think we ought to encourage the kind of development that we have been talking about in the way of getting citizens to take action in the program.

Some of these things cost very little money really, and examples were given during these hearings, but these are by no means the only things that individuals can do. There is the problem of food supply, for example. There is a problem of the recovery of farmlands. We need much more research on just how we can recover contaminated farmland and return it to usefulness.

I must say that what little work we have done so far has not led us to believe that it is a very easy job. But there may be things we have not discovered, which can be done to help greatly.

We have logistic problems in the case of an attack which need further analysis. We talk about country A and country B, but the country B is used to depending on the cities in its livelihood. And with the evacuees that Mr. Kahn mentioned from country A to country B, it has a doubly difficult problem of just continuing to survive. In thinking about these ordinary problems from the point of view of the individual as well as from the Government point of view, a dual attack on it will lead to some increase in the public knowledge of the threat and then our democratic processes will operate to give us a national position which the people can back and understand.

Chairman HOLIFIELD. The question has been asked the Chair why have we had testimony on post-protective measures? The Chair would like to state that, of course, this committee does not have civil defense under its jurisdiction. We felt that in presenting a picture of an attack like this to the American people, it was our obligation not to paint a picture which we believed is realistic even though it be black, and yet not say that there is some hope.

We did not, of course, bring these protective measures into the hearing as an indication that we favored building a maginot line in America or any of those sort of things.

It is very difficult to hold a hearing in which someone doesn't criticize the method of the hearings or the motives of the hearings.

We felt that it was to balance the testimony, as nearly as the facts seem to be to people who have given a great deal of study to it, that this point should be brought into the hearings before we close.

And that is the answer to that.

I have also been asked the question why the detailed effects of this pattern of attack were applied to our own country and not to some country overseas. The obvious answer to that is we are primarily concerned with the safety naturally of our own inhabitants. There is also the corollary factor that we do not want to be accused of proposing a war plan against another country; this committee doesn't. Then, following that, the question has been posed, Why did the pattern contain 2,500 megatons on our overseas bases and on a post-attacking nation? This was done on the same basis of reasoning as the original pattern, strictly for the purpose of obtaining the readings

on what a global deposit of this amount of megatonnage would result from the fission yields. We gave consideration to it for that purpose because we felt it would be unrealistic not to plan an offsetting attack.

We didn't, of course, go into any detailed planning on the casualties that might occur overseas. I think it would be reasonable to assume that if 2,500 megatons were distributed overseas on our bases and on a possible enemy, the casualties would go beyond probably the casualties here in our own country.

And, of course, this would assume a similar attack condition and similar population conditions in the areas attacked. I believe those are the three things that have been asked of the chairman.

Senator HICKENLOOPER. Mr. Chairman?

Chairman HOLIFIELD. Senator Hickenlooper?

Senator HICKENLOOPER. Of course, this is a vital and an important discussion. We on this committee have been quite aware of the substantial potential dangers in the various suggestions for taking advantage of it, or for protecting ourselves.

We have a very eminent panel here today of experts. I wonder how many of you gentlemen have shelters in your basements or other places with a food supply and the geiger counters and the oxygen and the various other things. Maybe that is an unfair question, I don't know. I am frank to say I don't have, and I have been at this for quite a little while.

Dr. LIBBY. I am going to have in my new home, Senator.

Mr. KAHN. I would like to comment on that. The Government depends so much on education that I used to make the following observation to education enthusiasts: "It is very difficult to educate anybody much more than I am educated and I don't have a shelter. Education really won't work." That was a joke, but I am now getting a shelter. But that is not the point.

I agree with Dr. Libby's program. It is a positive step except for on thing. Education programs look cheap and they look easy and so they look like a substitute for even say $500 million, and that is the danger of an education program.

Dr. LIBBY. I didn't mean that the citizens' program could do more than supplement Government effort, but we have all seen how difficult it has been to move in the Government's field, and so I think we might move in the citizens' field and maybe that will help move the whole thing.

Senator HICKENLOOPER. The point I was making, Dr. Libby, is I wonder if the argument has not been that we ought to start moving the individual before we get the ponderous Government into operation.

I just wondered how far the individuals had moved in this matter, especially when the individuals are acutely aware of at least the latest thinking on this?

Dr. LIBBY. You take this matter of new construction. Now you know we either have now or should have before long adequate architectural information so that it would be possible to say how to build a housing development so as to assure at least a reasonable amount of fallout protection and some blast protection, perhaps, for the people who live there. Well, this is for our local action on the community level, as is going to be done in a given area presumably the local community will require it.

As you know the Federal Government has required that Federal buildings be looked at from this point of view, and I think if we can get the citizens interested and get them to realize that this is not going to cost too much and is really in some senses beneficial in other regards, they will do it.

And then we will have city ordinances and laws on the local level which will encourage this kind of thing. And this could grow. And with this development people will be much better able to indicate to their representatives in the Congress what kind of action they will stand behind.

Senator HICKENLOOPER. Of course, I realize the necessity of that kind of an educational proposition, but I am getting right down to the individual now. You all realize this. Are we like the doctor who puts out one cigarette and picks up another and says to his patient, "You ought not to smoke so much," or have we got these things in our own basements now or in our own locations? And we start with food and are we doing it individually on this low-cost basis which can be done as an individual, and then rather expand that idea to the general public? It is a whole lot like soil conservation? We haven't got soil conservation established in the country until we have demonstrations around where one farmer is a little more successful under this program. But it has to be the individuals who do it first. That is the burden of my question.

Just how many of those of us who have been exposed to this necessity a little bit have really taken our own medicine?

Chairman HOLIFILED. Mr. Strope.

Mr. STROPE. I wish I could address myself to Senator Hickenlooper. I of course have studied the defense problem for a long time and I do have a shelter in my home. It is a crude one. It is the best place available. It has food and water and it has radiation instruments and I have instructed my wife and children on how to handle them when I am not there.

But I am a little bit embarrassed about this in a sense because I am one person who, as a result of his work, has convinced himself that civil defense is not a do-it-yourself project, and I do not believe, even though I have done this, that I have done anything significant.

Chairman HOLIFIELD. Mr. Corsbie?

Mr. CORSBIE. I think, Mr. Chairman, that we have handicapped our program by a concept of shelter that protects against everything.

Now, just as in your daily activities, in this a man must take some risk. What is the risk of riding a taxi across Washington? I have an idea that such risk, as far as I am concerned, is about the same as being exposed to 1 p.s.i. If I can then determine a thermal radiation level of comparable risk and levels of ionizing radiation which I think are no greater risk than some of the other things I do every day, and if we have a public education program that is successful, I predict people will begin to think about how much such insurance can they afford. If you get this problem back to a matter of decision on the basis of protection for the individual's family and himself, it is quite possible that a great deal could be achieved through the different degrees of protection provided by such individuals, each man doing what he can afford to do.

Chairman HOLIFIELD. Mr. Kahn, I believe you spoke once on this.

Mr. KAHN. Let me just add some comments to what Dr. Libby said. If the Government is really to advocate self-help programs in good faith, the citizen then has a right to ask, "All right, what about 2 weeks after the war is over? Will I then be able to live in the society that is there?"

Now this country supported about 1 million Indians before the advent of civilization and they had a lot of buffalo, you understand.

You haven't got the buffalo any more, and you had better have something to replace it.

Unless you believe that even if we literally do nothing at all in the way of preparations that the A country can still be rebuilt, then private preparations are inadequate. By the way, we can't prove that it can't, but we find the proposition dubious.

We know of many cheap ways in which recuperation would be facilitated by things that the Government could do.

The citizen just can't do it all. I would like to make one other comment. I think OCDM—and I hate to say anything uncomplimentary about OCDM because everybody else does and OCDM really does a pretty good job given the resources they have—has made one mistake. They don't study blast shelters any more because it is not part of the national policy.

Now we know in every other military program that it makes a great deal of sense to have much broader research and development programs than your current policies would call for. You need a menu to pick from in the future. It is easy for me to imagine wars in the future, and again I wouldn't say whether this future is 2 or 20 years, where a single bomb could take out 3,000, 4,000 square miles.

You live in a million square miles in this country. Now a little arithmetic tells you 300 bombs will then do the job. In other words, the enemy can cover large areas with one or two p.s.i. if he tries. If you have a system which is vulnerable to one or two p.s.i. and if it is all you are thinking of building, it may be obsolete in a relatively short time.

Moderate blast protection may not be very expensive. For example, if you talk about the kind of shelters which Jerry talks about, you can make them 25 to 50 p.s.i. very cheaply. If you make them about five times as big, it is almost free, to build in blast protection.

Chairman HOLIFIELD. The Chair would like to step out of context as chairman and, for the moment, be a witness. I think the question that Senator Hickenlooper asked is a good question and should be considered.

I live in an apartment house in Washington with no other shelter but an ordinary basement. In California I only have access to an ordinary basement for shelter. But this does not mean that I do not see the hand. This means that I have a different concept.

I believe that the Federal Government has the constitutional obligation to protect its citizens from enemy attack.

This does not mean that the citizen is completely immobilized and does nothing, any more than it means a civilian cannot be called up to be a soldier and then have to perform all military duties. But the concept of nuclear war is so great that I maintain it cannot be solved on an individual basis. This does not mean that individuals can't do things.

They can. But it means you should have a national program which makes sense to the American people. A man should no more be required to meet the hazard of a 10-megaton bomb than he should be required to go out with his bare hands and fight a B-52, or a group of machine guns. If the constitutional obligation is to use soldiers to protect the people of the United States, there is also a constitutional obligation, in my opinion, when the home front becomes the battlefront for the Federal Government to recognize this fact.

Now it has not been recognized adequately, although we do have our OCDM, we had FCDA. It has never been recognized adequately to meet the challenge, in my opinion, of active war by calling upon the resources of the Nation to support our military forces.

I believe it is just as vital to protect the home front as it is what used to be the battlefront. Today the home front will be the battlefront in the case of this kind of war we see in the nuclear age.

That would be my answer. I have no desire to live in a world where 50 million of my neighbors have deen destroyed all around me. I would be too busy burying corpses.

And if this is a national hazard, then I would say it is the Federal Government's obligation to take the initiative and do the main things that are necessary.

I believe if that leadership is given by the Federal Government, the American people will respond to it and will pay the taxes necessary to take care of this hazard just the same as they are now paying more than $40 billion a year to meet a military threat.

Senator HICKENLOOPER. Mr. Chairman, I will also say that that is a modern theory, that the Federal Government should do everything for everybody and that the individuals should sit back and wait for the Federal Government to do it, but I am coming back to the old days when a man got the rifle off the mantlepiece and protected himself before the soldiers got there.

He shot it out lots of times and I think usually he probably did more than the Federal Government did to establish a little peace and quiet.

Now we have a whole lot different situation here.

The Federal Government has a tremendous responsibility. I wouldn't deny that for a minute. We have gone pretty far afield from my original question which is how many of us have taken our own medicine and have got shelters of our own against the little individual family unit, which can also be protected as well as the mass protection? I don't think I will take any more time to pursue this matter now.

Representative HOSMER. Mr. Chairman, as long as we are getting philosophical, I think we must realize that the business of living is a risk in and of itself.

In the number of risks we take we can make a choice. Others we have no choice. Others are involved in the way a man handles his relations between nations. In that we have a degree of choice but not an absolute discretion.

I agree with the chairman that the duty of the Government is to minimize to the greatest extent possible whatever risk, that it is capable of minimizing, and I think, rather than throwing up our hands in despair or digging our holes deeply into the ground, that these

hearings if they have done nothing else have emphasized the necessity of very wisely proceeding with the business of minimizing those risks.

Now that doesn't mean giving up because that bears a price tag that is greater in my mind than the risk of nuclear war.

It does mean, however, going about in relaxing world tensions in a manner which will accomplish it, not in the pursuit of an illusion of peace but in a pure suit of a practical means of achieving it. And that often requires courage and wisdom and chance taking in and of itself.

I think this Nation is capable of doing that. We are not the first generation of Americans who have faced difficult choices.

The choice between slavery and possible death. I think we are as I say capable of handling the situation, running the risk and avoiding the sad choices.

Chairman HOLIFIELD. Dr. Kahn, let's plan to close the hearing in a few short minutes.

Dr. TOMPKINS. I would like to put into the discussion if I may just a few personal views of my own as to what the nature of this problem is.

I had the experience of being on the Manhattan District in 1943. I am very familiar with the psychology of revulsion against the effect these weapons can produce. As a matter of fact, I was part of a group which shortly after 1945–46 attempted in our own minds to conceive of an attack just about the kind that you have laid down. It is entirely true that in the absence of experience, in the absence of information and in the absence of data, the impression that all of us have as to the consequences of such an attack were virtually of the complete and total saturation variety, namely there would literally be nothing left after such an event.

Now this was 10 years ago. After that period it became quite apparent, at least to my mind, that an event such as we have examined here is not one that anyone would take willingly, but which we would be very smart to ask ourselves if it were imposed on us would we be able to come through it?

Now this is a different question. This is my view of the role of civil defense.

I don't think any of us will accept this kind of result willingly unless the stakes were well beyond our individual choices. That isn't the role that nonmilitary defense plays in at least my life.

With the passage of time, that is since the 1945–46 period, we have examined the results of a very major attack. We have found in these hearings what from 10 years' experience I know to be true, namely, the results are catastrophic enough in their own right. They need no imaginary amplification. The facts themselves are bad enough. However, it is crucially important to look those facts squarely in the face if one is going to face the necessity for survival, if against your will or despite anything you can do about it, it is imposed on you. As far as I am concerned, if the chips ever go down and avoiding a conflict is not possible in the scheme of human events of the future, I for one do not propose to see this Nation come out the loser.

And therefore, I think we should be able to take it if we have to.

Now following up Herman's point of view, I think the technology is such that complete protection is absolutely out of the question.

Therefore the concept that any protective measures that we take puts us in the position of adopting a maginot line concept behind

which we hide, or developing ourselves into fortress America is entirely false. That is not the role of the nonmilitary defense in the world of the future.

The world of the future is going to be dangerous. The human capacity to inflict such damage will inevitably be there. The threat of the employment of that damage is something with which we will have to live unless something very drastic changes in our international relations. We must know how to react to it. I personally never exject to see consequences of the type displayed on these maps. If we really thought this, if we really thought that there was no hope of getting around it, then I think one would be entitled to be discouraged.

As far as I am personally concerned, by looking at the problems, understanding what they are composed of, and by necessity being an incurable optimist, I never expect to see a war of this kind happen. It is possible that more limited engagements of a more sharply defined type will be fought under the sword of Damocles hanging over our heads some time in the future. If so, let us be prepared for that. So, that at least, is my personal view as to the role that the nonmilitary defense should play, and it will never be perfect.

Chairman HOLIFIELD. Many of the witnesses who have appeared before this committee this week and the members of this committee have for many months and years been carrying a heavy burden of responsibility of knowledge of these things on their minds and in their hearts.

Some of us have felt that it is time to share this burden of responsibility with the American people. Before we adjourn I want to thank the reporters who have attended these hearings so patiently and the people on the TV and radio, the representatives in those media. I want to thank the members and especially I want to thank Mr. Hosmer, because I believe he sat in his chair as many hours as I have sat in mine.

I want to thank the staff, which has worked on this hearing some 6 weeks. Particularly do I want to thank Colonel Lunger who has worked many nights to 2 and 4 o'clock in order to make these hearings possible the next day and also Dr. Carey Brewer whom we borrowed from another subcommittee, the Subcommittee on Military Operations, for these past few weeks.

I want to thank the audience too that has attended these hearings and compliment them on the way they have listened, attentively and quietly, to the sometimes long, complicated, and technical testimony that has been given in some instances.

These long technical testimonies were necessary in order that the basic record might be presented in as fair a way as we know how.

In conclusion I want to say the challenge of the nuclear age is enormous and inescapable.

The facts of nuclear war and the effects of nuclear war once established will not fade away because they are unpleasant. If we are prudent we will not ignore them.

They will not disappear. Each of us must accept personal responsibilities because the nuclear war is a personal threat to our survival.

The problem is too large to leave solely in the hands of the diplomats and the generals. They need the collective thinking and advice of every thinking human being in the world.

It may well be that the time has come in man's long history when he must choose between the arms race and the human race.

Representative HOSMER. Mr. Chairman, just before you close, I would like to add my personal word of commendation to the representatives of the news media who have done what I feel to be a straightforward job of reporting these hearings fully, fairly, without sensationalism, and in so doing I think they have performed a distinct service to the American people and the people of the free world. Thank you.

Chairman HOLIFIELD. The meeting is adjourned.

(Whereupon, at 4:05 p.m., Friday, June 26, 1959, the hearing was adjourned.)

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APPENDIX

BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

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BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

SUMMARY-ANALYSIS OF HEARINGS
JUNE 22–26, 1959

JOINT COMMITTEE ON ATOMIC ENERGY
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SUMMARY-ANALYSIS OF HEARINGS ON BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

I. Introduction

For the first time in history American communities have become a part of the main battlefield of a possible future war. Only on few occasions in the past have American homes and civilians been endangered by armed conflict, and never has there been a threat of wholesale destruction and loss of life such as that now posed by a powerful and ruthless adversary armed with nuclear weapons. The subcommittee believes that the American people, whose homes and lives are now threatened, have a right to know the basic facts of nuclear warfare within the bounds of security restrictions.

Beginning on June 22, 1959, the Special Subcommittee on Radiation held 5 days of public hearings on the biological and environmental effects of a possible nuclear war. The subcommittee's purpose was to establish a public record clearly setting forth the scientific facts concerning the probable physical and biological effects of such a war on man and his environment. To the subcommittee's knowledge, this is the first time any comprehensive presentation of such facts has been made to the American people or to the people of any other nation.

The scope of these hearings did not include consideration of the overall impact of nuclear war upon the Nation's economy, specific recovery measures, or the problem of industrial recuperation in the long-range postattack situation. Nor did the subcommittee consider the controversial question of governmental or individual responsibility for financing a national civil defense system.

At the outset the subcommittee wishes to note also that these hearings were not designed to determine the exact form of a possible future nuclear war or the likelihood that such a war will occur. Nor does this report contain any such predictions or conclusions.

It is believed that the data presented in these hearings and summarized in this report will enable the American public to understand more clearly the basic scientific facts of a possible nuclear war and to achieve a better appreciation of the fundamental issues of our national security program.

In the course of the hearings the importance of understanding the facts of a possible nuclear war was underscored and reemphasized by numerous expert witnesses. Simply to understand that "unprecedented destruction" is *not* the same as "unlimited destruction"—as one witness pointed out—is crucial to intelligent discussion of the issues.

At the same time, no one appearing before the subcommittee attempted to minimize or make light of the terrible destructiveness of nuclear weapons. Rather, every effort was made to achieve an ob-

jective appraisal of weapon effects through a step-by-step examination of the problems by competent witnesses based on quantitative computations.

Although the testimony emphasized many of the uncertainties of nuclear war, it was noted that the relevance of quantitative estimates today is most impressive. It was pointed out that modern science makes possible greater accuracy in predicting what a nuclear war would be like.

Moreover, quantitative estimates make possible more precise thought and more accurate communication in a subject field fraught with misconceptions and emotional, moral and spiritual issues. Although such estimates when presented in an objective manner, may erroneously imply a disregard for, or callousness toward, moral and spiritual values, they are nevertheless essential to an objective consideration of the basic facts. It is fully recognized that facts about nuclear carnage are not pleasant. It is without precedent that a committee of the Congress analyzes casualties on the scale encountered in nuclear war. But the subcommittee had no choice but to face up to these grim facts.

The subcommittee believes that the fundamental issues dealt with in these hearings are extremely serious, and that they are issues which need to be understood, considered and discussed. As stated by one witness:

> If you are afraid to discuss the issue, you will certainly be afraid to meet the crisis if and when it occurs.

It was apparent from the hearings held by this subcommittee in 1957,[1] that there is a very large practical difference between the problem created by the world-wide fallout coming from a program of testing nuclear weapons, and those that would result from the use of these weapons in an all-out war. Accordingly, the fallout problems associated with the testing of nuclear weapons were considered in a separate hearing[2] early in May of this year, with the problems of nuclear war being investigated in the June hearings.

The contrast between the two types of problems may be illustrated by a few examples. All the test programs of the U.S.S.R., Great Britain, and the United States to date have involved the detonation of approximately 170 megatons of total yield, of which about 90 megatons have been fission yield. These test detonations have occurred over a 10-year period at different latitudes and under varying climatic conditions and have consisted of surface bursts, tower bursts, underwater bursts, and air bursts at high and low altitudes.

The problems considered in the June 1959 hearings involve the hypothetical detonation of approximately 4,000 megatons total yield, of which approximately 2,000 megatons constitute fission yield, all consisting of surface detonations occurring within a period of 1 day. This was accepted as a realistic possibility should a nuclear war come.

The test programs to date have been conducted at remote places—in Australia, at isolated Pacific islands, in Nevada,[3] and inside the Soviet Union. Therefore, we have been primarily concerned with

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[1] Hearings on the "Nature of Radioactive Fallout and Its Effects on Man," May 27-29, and June 3-7 1957.
[2] "Fallout From Nuclear Weapons Tests," hearings held by the Joint Committee on Atomic Energy, May 5, 6, 7, and 8, 1959.
[3] Kiloton size only.

material drawn into the troposphere and stratosphere and the subsequent worldwide deposition of the radioactive debris.[4] In the June hearings we were concerned with hypothetical detonations in the midst of cities and military bases. Consequently, it was necessary to consider the far more severe immediate and local effects—blast, thermal and radiation—which, under conditions of the test programs, to date, would not be encountered normally.

The biological effects of the radioactive fallout resulting from the test programs to date are so slight that they must be evaluated on the basis of an estimated increase in the incidence of naturally occurring effects, such as leukemia on the one hand or inherited effects such as abnormalities or stillbirths. Under conditions of nuclear war, we are concerned with problems of immediate survival of the millions of people who may be subjected to radiation exposures as severe as or greater than those received by a few individuals accidentally exposed to momentary but high intensity radiation in Government research operations.

In order to consider the problems of a possible nuclear war, the subcommittee prepared a hypothetical attack situation in which nuclear weapons of varying sizes were placed on specific targets within the United States. In addition, a specific total weapons contribution was arbitrarily assigned to other areas of the Northern Hemisphere to take into consideration also the worldwide fallout resulting both from a hypothetical retaliatory attack by the United States and from an enemy strike against U.S. overseas bases.

Having established this basic framework, the subcommittee then prepared a topical agenda and invited a distinguished and competent group of experts, to present testimony on the probable biological and environmental effects of such an attack on the United States.

No classified information was used in developing the subcommittee's hypothetical attack assumptions, and to insure against the possibility of any direct or indirect inferences to existing classified war plans or weapons stockpile information, the subcommittee refrained from requesting the support of any Department of Defense agency in establishing the attack pattern.

The attack situation, including the sizes of weapons and their distribution on specific targets, was carefully developed by the subcommittee and represents assumptions considered realistic. However, the subcommittee has no wish that the assumed attack be taken as representing anything more than a hypothetical example. Other attack patterns of greater or lesser total megatonnage could have been planned and, by the same token, extrapolations from this specific pattern (and effects) can be made upward or downward. The purpose of the subcommittee's particular attack assumptions was to set forth a uniform basis and framework for analysis by the various individuals asked to testify or submit statements for the subcommittee record.

The Office of Civil and Defense Mobilization cooperated to the fullest extent in depicting the subcommittee's attack assumptions on maps, charts, and other visual aids and in computing structural damage and human casualties on the basis of the subcommittee assumptions.

[4] It should be noted, however, that the May hearings were also concerned with phenomena related to local "hot spots" resulting from radioactive contributions to the atmosphere by the test programs.

The resources of the Atomic Energy Commission, its personnel and unclassified publications, were made available by Chairman McCone and were of great value to the subcommittee.

The subcommittee also utilized a mass of unclassified data furnished by other governmental and private sources on the effects of radiation. A special mention of appreciation is due Dr. Paul Tompkins and his associates of the U.S. Naval Radiological Defense Laboratory. Much of the basic data presented at the hearings was derived from the work of the USNRDL, and Dr. Tompkins and his staff consulted freely with the subcommittee throughout the hearings and during the preparation of this report.

The witnesses presenting testimony were selected on the basis of their competence and experience in the different fields of nuclear phenomena, with particular emphasis on nuclear weapons effects.

In the biomedical field the subcommittee received testimony from those scientists and technical personnel having the broadest experience in laboratory work on test animals and in the treatment of human beings exposed to radiation at Hiroshima and Nagasaki and in the accidental contamination of the Marshall Islands.

For the consideration of structural damage from blast and fire and of other weapons effects, outstanding authorities presented their findings and the latest available scientific data.

The weather patterns and other meteorological data for the date of the hypothetical attack were established by experts of the U.S. Weather Bureau, supported by their worldwide organization.

The reader is encouraged to examine the full testimony and supporting data of each witness in the printed record of the hearings. In this report the subcommittee has endeavored to present a faithful and concise summary of the data and to highlight the key issues for the convenience of the public and the Congress. Naturally, these data and issues are more completely set forth in the verbatim hearing record.

II. Summary

THE HYPOTHETICAL ATTACK

The hypothetical attack set forth by the subcommittee assumed that 263 nuclear weapons in 1, 2, 3, 8, and 10 megaton sizes with a total yield of 1,446 megatons [5] were detonated on 224 targets within the United States. An additional 2,500 megatons were assumed to have been detonated elsewhere in the Northern Hemisphere in attacks on overseas U.S. bases and in retaliation against the aggressor homeland. All weapons were arbitrarily designated as having a yield of 50 percent fission and 50 percent fusion. A weapon with 50 percent fission yield is one in which 50 percent of the total energy (yield) is derived from the fission process. Nuclear fission refers to the splitting of heavy atoms such as uranium and is the primary source of contamination of radioactive fallout particles.

[5] A 1-megaton bomb has the same explosive energy release as 1 million tons of TNT. The Hiroshima bomb yield was estimated at 20,000 tons of TNT, or 20 kilotons.

CASUALTIES AND DAMAGE TO DWELLINGS

The expert testimony and supporting scientific data presented at the subcommittee hearings indicate that under present conditions such an attack would have cost the lives of approximately 50 million Americans, with some 20 million others sustaining serious injuries. More than one-fourth (11.8 million) of the dwellings in the United States would have been destroyed and nearly 10 million others would have been damaged. Some 13 million additional homes would have been severely contaminated by radioactive fallout. Altogether, approximately 50 percent of existing dwellings in the United States would have been destroyed or rendered unuseable for a period of several months.

Although the weapon detonations used in this exercise were designated as surface bursts, which would maximize the local radioactive fallout hazard, nearly 75 percent of the deaths would have resulted from the blast and thermal effects, combined with immediate radiation effects. Only 25 percent of all fatalities would have resulted from fallout. At the same time, more than half of the surviving injured would have radiation injuries.

Most of the damage sustained by dwellings would have resulted from the blast and thermal effects.

BIOLOGICAL EFFECTS

The three casualty-producing phenomena of nuclear weapons—blast, thermal, and radiation—occur in varying combinations, depending on proximity to the point of detonation. At close range one would encounter all three, including fallout radiation as well as immediate radiation from the fireball.

1. Blast effects

Blast produces primary effects resulting from the blast wave itself (lung damage, rupture of eardrums); secondary effects, resulting from flying fragments (loose debris, building materials) propelled with great force by the blast wave; and tertiary effects, resulting from the body itself being thrown violently by the blast wave. In addition, miscellaneous injuries will result from conditions created by the blast on surrounding objects (e.g., broken gas mains, downed power lines).

Approximately 95 percent of the blast casualties produced by a 10-megaton weapon will result from the secondary and tertiary blast effects. For this size weapon the secondary effects are important to a distance of 11 miles; the tertiary effects can occur to distances of from 7 to 16 miles.

2. Thermal effects

Thermal effects consist of fires caused by direct ignition of combustible materials, skin burns on exposed portions of the body, and temporary or permanent blindness from the intense light of the fireball.

In the hypothetical attack situation posed by the subcommittee, thermal effects, including the hazard of mass fires ("fire storms"), could extend over large areas, in some cases up to distances of 20 to 25 miles from the point of detonation.

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3. Radiation effects

The most severe form of radiation injury, under conditions of nuclear war, would be that resulting from severe exposure to the primary radiation "flash" (close to ground zero) or that attending whole body exposure to close-in fallout during the first day or so. However, severe irradiation could occur as a result of prolonged exposure to local fallout even after the first day unless survivors were provided with adequate shelter protection. Direct contamination of the skin with fallout debris could produce painful "beta burns" due to the action of beta rays irradiating the skin and outer layers of the body surface. In addition, there is an internal hazard of radioactive material which gains entry into the body through inhalation, ingestion, or through open wounds.

(1) *Acute effects.*—Instantaneous radiation doses of 5,000 roentgens or greater immediately produce symptoms of shock; death occurs within hours.

Radiation doses of 1,000 to 5,000 roentgens produce nausea and vomiting, fever and general fatigue within a few hours. Temporary recovery is followed within 1 or 2 weeks by reappearance of symptoms and probable death.

Exposure to doses of 200 to 1,000 roentgens causes nausea and vomiting within a few hours and in the period of from 2 to 4 weeks after exposure major changes will occur in the composition of the blood, rendering the body particularly susceptible to infections during this time. Approximately one-half of those exposed at the level of 450 to 700 roentgens would be expected to recover if not subjected to additional physical stress or radiation. The other one-half would die within 2 to 4 months. Probability of recovery increases greatly at levels below 450 roentgens.

Radiation doses of 200 roentgens or less will produce only mild symptoms of nausea and vomiting. Changes in the blood may occur later, but individuals so exposed usually will not require hospitalization.

(2) *Effects of protracted radiation.*—Higher radiation doses can be tolerated by the body without developing symptoms of acute radiation illness if exposure is spread over a longer period of time. Approximately 90 percent biological recovery can occur with continued or repeated exposures, but the remaining 10 percent nonrepairable injury may produce late effects, such as cancer, over a period 20 years or more.

When only a part of the body is exposed, the ability to recover is greatly increased. For example, the exposure of a person's legs alone to 500 roentgens of radiation would not result in a lethal dose.

The probability of increasing the incidence of leukemia and other types of cancer is considered proportional to the average total radiation dose sustained by the surviving population. Potential deaths from this cause are estimated as about 2 percent of the deaths attributable to acute radiation injury. These deaths will be spread out over a period of decades since it is a characteristic of radiation-induced cancer to be long delayed after incidence of injury.

(3) *Skin burns from fallout.*—Skin burns can be caused by beta rays from the fallout particles coming in direct contact with the skin. However, very large doses of beta radiation are required to produce severe burns, and the particles may be removed from the skin by good

personal hygiene. Though less a threat to survival than whole body gamma radiation, beta burns can create open lesions which are easily infected.

(4) *Inhalation and ingestion hazards from fallout.*—Limited data suggest that inhalation (through breathing) and ingestion (through eating and drinking) of radioactive materials would in general constitute a relatively small hazard in comparison with total body radiation from the fallout field itself. The testimony indicated that this type of exposure would not become a major threat to survival in the immediate postwar period.

(5) *Genetic effects.*—The study of genetic effects of massive radiation on man is very limited. There is considerable evidence that the radiation exposure of a nuclear war would greatly increase genetic mutations for some succeeding generations. However, the widespread argument that the ultimate genetic consequences could lead to the virtual elimination of the human race is not supported by the testimony. The concensus of expert testimony was that the race could and would survive the type of hypothetical attack considered in these hearings, notwithstanding the inevitable costs in physical impairments and deaths due to additional genetic mutations.

ENVIRONMENTAL CONTAMINATION

A subject of major importance to the surviving population of a possible nuclear war is the consequences of introducing large quantities of radioactive materials into the environment. Three main categories of effects were considered with respect to environmental contamination: effects on animals, effects on food supplies, and long-term effects.

1. Effects on animals

It is quite probable that very large numbers of animals used as a source of food would be killed by exposure to fallout. Many mammals have an LD–50 [5a] in the range of 500–1,000 roentgens and since they would be provided with little shelter, fallout would be expected to exact a heavy toll. However, surviving animals might well serve as a source of food, freer from radioactivity than other foods, if the flesh is eaten and certain organs and milk are discarded or used only as animal food.

Although some animals may incur increased incidences of disease due to lowered body resistance, radiation doses in the lethal range are necessary to impair fertility. The deleterious effects of genetic mutations in these animals could be ameliorated by the practice of selective breeding.

2. Effects on food supplies

Food crops already harvested and not destroyed by blast and thermal effects may become contaminated by local fallout. However the radioactive particles can normally be removed.

The principal barrier to the recovery of growing food crops would be the shortage of fuel and machinery, together with the radiation hazard to workers.

In general, if the external gamma radiation level permits the growing, harvesting, and processing of foods, the corresponding threat of radioactivity in this food when consumed would not impair survival and recovery from the attack. However, in zones of heavy local

[5a] Lethal dose for 50 percent of those exposed. Cf. pp. 13–14.

fallout decontamination would be required to reduce the strontium 90 content of the soil to a level acceptable for production of some food crops and milk.

3. Long-term environmental effects

Although much remains to be learned about the long-range impact of a nuclear war on "the balance of nature," the concensus of the testimony was that, despite the severe shock, life would continue and full ecological recovery would eventually occur.

ADDITIONAL DATA ON RADIOACTIVE FALLOUT

Several additional factors presented to the subcommittee with respect to radioactive fallout are considered highly important.

(1) The worldwide strontium 90 fallout resulting from the assumed attack would not pose a major survival problem in countries not attacked. The level of strontium 90 deposited from long-term fallout would be higher than the maximum permissible concentration recommended for the population as a whole on a peacetime standard, but lower than the recommended maximum permissible occupational dose under controlled conditions.

(2) The actual release of gamma radiation energy from fission products differs significantly from that represented by the standard formula ($t^{-1.2}$ rule) contained in the official Government publication, "The Effects of Nuclear Weapons." New calculations indicate that early dose rates will be of greater intensity than previously believed and that over a long period of time the rate of decline will be more rapid. While the problem of immediate survival in a nuclear war is thus increased, the problem of long-term recovery is reduced.

(3) Local fallout is significantly affected by wind and weather. Actual fallout contours will differ markedly from the idealized cigar-shaped patterns normally used as a basis of estimating fallout effects. Moreover, peak fallout intensities will almost never occur at or near the point of weapon detonation. For example, the maximum fallout intensity for a weapon of a 5- to 10-megaton yield may appear at a distance as great as 60 to 70 miles from the point of detonation.

SURVIVAL MEASURES

Probably the most significant finding presented to the subcommittee was that civil defense preparedness could reduce the ~~casualties~~ of the assumed attack on the United States from approximately ~~30~~ percent of the population to about 3 percent. The provision of shielding against radiation effects would at the same time protect against blast and thermal effects for the vast majority of the population.

The cost of providing high-performance shelter protection for 200 million people was estimated at between $5 billion and $20 billion.

The main conclusion presented to the subcommittee was that the country must have a national radiological defense system if the Nation is to withstand and recover from an attack of the scale which is possible in an all-out nuclear war.

On page 8, beginning at the 12th line from the bottom; ...
should read:

"Probably the most significant finding presented to the subcommit[tee] ... that civil defense preparedness could reduce the fatalities o[f] ... the United States from approximately 2... The provision of shield... against...

STRATEGIC IMPLICATIONS

In the course of the hearings the subcommittee received testimony on some of the strategic implications of the scientific data presented. A digest of this testimony and related panel commentary is included in an addendum to the report.

III. The Attack Pattern and Basic Assumptions

The attack pattern and basic assumptions established by the subcommittee for consideration in these hearings reflected an attack against the United States on a limited scale. That is, the number and total megatonnage of weapons employed were less than the maximum which a potential enemy is capable of launching against the United States.

At the same time, the pattern of the hypothetical attack was designed for a greater dispersion of weapons than would obtain in a so-called "limited" attack directed only against U.S. strategic offensive forces.

Although no classified information was utilized and the attack pattern was developed without assistance from any governmental agency, the realism of the assumptions was confirmed at the request of the subcommittee by competent military experts.

The targets in the United States were selected on the basis of criteria used by the Office of Civil and Defense Mobilization in its unclassified civil defense exercises and from published lists of military bases and Atomic Energy Commission installations.

The hypothetical attack consisted of 263 nuclear weapons delivered on 224 targets in the United States. The total megatonnage (millions of tons of TNT explosive equivalent) of the attack was 1,446, consisting of weapons ranging in size from 1 megaton to 10 megatons, as indicated in the following table:

Table III—1.—*Weight of the attack*

Size of weapon	Number used	Weight of attack (megatons)
10 megatons	60	600
8 megatons	74	592
3 megatons	44	132
2 megatons	37	74
1 megaton	48	48
Total	263	1,446

Of the 224 targets, 71 were large industrial and population centers officially designated by the OCDM as "Critical Target Areas." Military installations constituted an additional 132 targets and the remaining 21 targets were Atomic Energy Commission facilities.

The following table indicates the dispersion of weapons among the several classes of targets:

TABLE III—2.—*Targets of the attack*

Type of target	Number	Number of weapons	Weight (megatons)
Air Force installations	111	111	645
Critical target areas	71	110	567
AEC installations	21	21	168
Army installations	12	12	24
Navy installations	5	5	28
Marine Corps installations	4	4	14
Total	224	263	1,446

All weapons were arbitrarily designated as 50 percent fission and 50 percent fusion weapons detonated at ground level, that is, with the fireball touching the earth's surface. Each weapon was assumed to have been detonated at or near its specified target by using a standard statistical method for random bombing errors.

The total of 1,446 megatons was considered the yield of the weapons detonated, not the gross attack which the aggressor force might have launched initially, and no attempt was made to "war game" the overall problem of weapon delivery, interception, and retaliation.

For purposes of computing worldwide fallout and its effects for a period of 5 years after the attack, again without war gaming, it was assumed that 2,500 megatons of weapons were detonated on areas of the Northern Hemisphere outside the continental United States, representing the net result of attacks on U.S. overseas bases and U.S. retaliatory strikes against the aggressor homeland.

The general distribution of targets in the United States is illustrated on the map in figure III—1.

The time of the hypothetical attack was set at 12 noon Greenwich time (7 a.m. eastern standard time) on a typical October day, which assumes completed harvest and storage of food crops in the aggressor homeland. The actual weather conditions used in plotting fallout patterns and determining the effects of meteorological factors were those recorded for October 17, 1958, a typical fall day. It was necessary to select a particular day in the past in order to provide the weather data for accurate calculations.

IV. Basic Effects of Weapons Employed

As indicated above, the weapons employed in the hypothetical attack assumptions consisted of 50 percent fission and 50 percent fusion weapons ranging in size from 1 to 10 megatons, all detonated at ground level. The following data concerning the basic effects of these weapons were presented at the subcommittee hearings. Later sections of this report will discuss the biological and environmental effects of these weapons in greater detail.

1. Partition of energy in a nuclear explosion

About 35 percent of the total energy of a nuclear explosion is given off as radiant thermal energy or heat, in much the same way as the sun radiates heat. Another 50 percent of the bomb energy is contained in the blast wave that travels several times the speed of sound. About

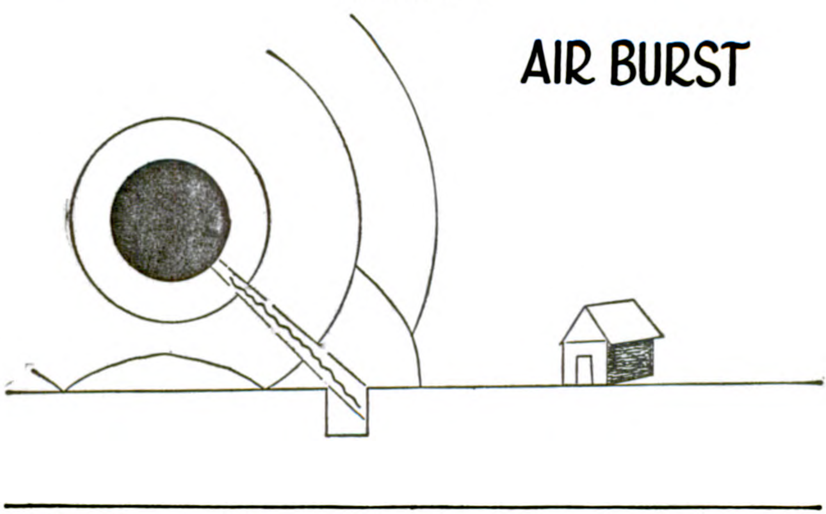
5 percent of the total energy is given off directly from the exploding bomb as prompt nuclear radiation in the form of gamma rays, neutrons and other particles such as alpha and beta. The remaining 10 percent of the total energy is released from the radioactive-fission products over long periods of time.

In the case of a large yield surface burst, such as the 10-megaton weapon used in the subcommittee's assumption, approximately 80 percent[6] of the fission products fall back to the ground to form the local fallout pattern. About 15 percent of the fission products from a surface burst remain high in the atmosphere (stratosphere) for very long periods of time (half residence time the order of a year or more)[7] and return to the earth's surface as worldwide contamination. Approximately 5 percent would be worldwide tropospheric (lower atmosphere) fallout in a band near in latitude to the point of detonation.

2. Differences in airbursts and surface bursts

Airburst.—An airburst is one in which the fireball does not come in contact with the ground. (See fig. IV—1.) In a large-yield airburst nearly all of the fission products are deposited in the stratosphere, thus making a maximum contribution to the worldwide fallout with essentially no local fallout. The blast wave is reflected and reinforced at the earth's surface. In general, the range of thermal and nuclear radiation received by ground targets will be greater than for a surface burst.

FIGURE IV—1

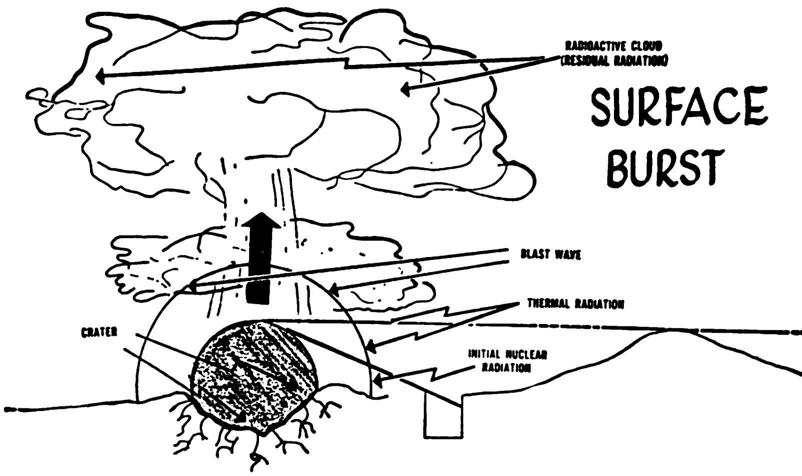


[6] The figure of 80 percent may be too high. Actually, there is very little experimental data on the percentage of fallout coming down locally for surface-burst megaton weapons. The 80 percent figure might well be 50 percent under some circumstances.

[7] The mean residence time is the half residence time divided by 0.7. The half residence time is the time required for the amount of material in the stratosphere to be reduced by 50 percent. These concepts are analogous to the mean life for radioactive decay.

Surface burst.—A surface burst is one in which the fireball intersects the surface. (See fig. IV–2.) Local fallout is maximized in a surface burst. A crater is formed in the vicinity of the burst and is highly radioactive. The range of thermal and nuclear radiation effects is reduced by the natural shielding of hills and buildings.

FIGURE IV–2



3. Nuclear weapons effects on materials and structures

(1) *Blast.*—Multistory brick apartment houses are quite vulnerable to the blast wave. All such structures would be destroyed within a radius of 7 miles from ground zero for a 10-megaton weapon and within 3 miles for a 1-megaton burst. Thus, a factor of 10 in yield changes the radius of destruction by about a factor of 2.

A well-constructed wood-frame house completely collapses within 9 miles from a 10-megaton surface burst and within 4 miles of a 1-megaton burst.

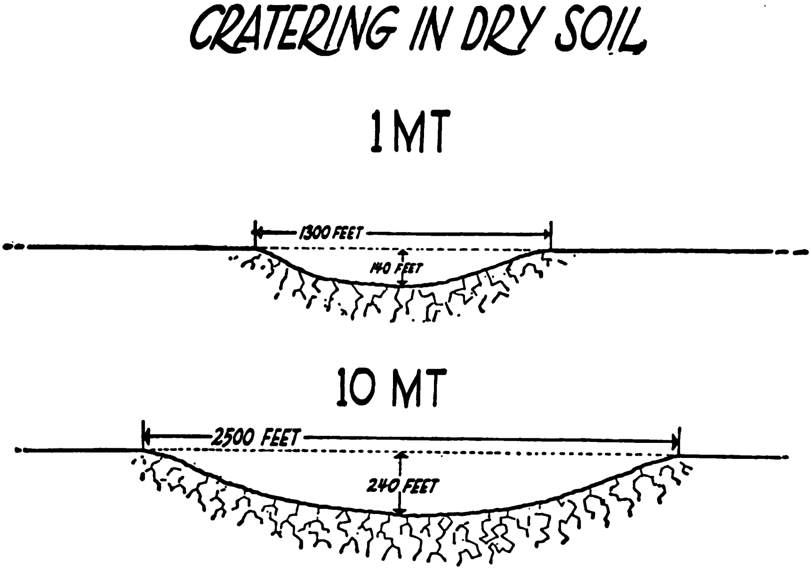
(2) *Thermal.*—Fires can be started by the ignition of light kindling materials anywhere within about 9 miles from a 1-megaton burst and within 25 miles from a 10-megaton burst. Thus, the presence of light kindling materials, such as trash, paper, and unpainted wood in a residential area will probably result in widespread fires.

(3) *Nuclear radiation.*—Initial nuclear radiation and fallout have very little effect on most inanimate materials. However, fallout can deny the use of inanimate objects to man until they are decontaminated by removing the radioactive particles.

(4) *Crater.*—Such hard structures as underground installations are quite invulnerable to the other effects, but can be destroyed by the cratering effect of a surface burst. (See fig. IV–3.) The damage would not be confined to just the crater dimensions, but would extend also into the rupture zone, a region having a diameter about twice the

crater diameter. Almost no structure nor its occupants would survive within this region.

FIGURE IV-3



4. Nuclear weapons effects on man

(1) *Blast.*—Blast overpressure in itself is not a significant casualty agent. However, the secondary effects and injury caused by crumbling buildings, flying debris, and man himself being thrown about, are certainly significant. Extensive blast injury can be expected at distances at which brick apartment houses collapse (7 miles from 10 megatons and 3 miles from 1 megaton). Extensive window breakage and flying glass would also occur at these and somewhat greater distances.

(2) *Thermal.*—Second degree burns of the hands or face will incapacitate an individual. For a 1-megation burst, an exposed person 9 miles from ground zero on a clear day can be expected to receive second degree burns on the exposed skin. For a 10-megaton burst, this range would be less than three times as great, or about 25 miles.

(3) *Initial radiation.*—Nuclear radiation is measured in units of rem (roentgen equivalent mammal). A rem is defined as the amount of radiation of any type required to produce a biological effect equivalent to that of 1 roentgen of X-ray. Two hundred rem will cause vomiting and nausea in 50 percent of a group of people by the end of the first day, but none or very few would be expected to die. A dose of 450 rem would cause vomiting and nausea in all of a group by the end of the first day, and according to the official handbook entitled "The Effects of Nuclear Weapons," [8] about half of the people so exposed would be expected to die within 30 days. This is termed the

[8] "The Effects of Nuclear Weapons," prepared by the U.S. Department of Defense and published by the U.S. Atomic Energy Commission, Washington: U.S. Government Printing Office, 1957.

"lethal dose 50 for 30 days" (LD 50). However, data suggesting higher dose rates for 50 percent were presented to the subcommittee and are discussed later in this report, beginning on page 37. When exposed to 600 rem the entire group would become sick within 4 hours and a very large percentage of them would soon die. With a dose of 1,000 rem, all would be incapacitated within 1 to 2 hours, and all would die very soon thereafter.

Nuclear radiation emitted directly from the exploding bomb within the first minute would be at least 700 rem within a range of 1.5 miles from a 1-megaton burst and within 2 miles from a 10-megaton burst. This is a prompt dose of radiation that certainly means death to the unshielded or unsheltered in this region. It is, however, a region for large-yield surface bursts where blast and thermal effects are also extremely hazardous or lethal to the unsheltered population.

(4) *Local fallout.*—Due to the assumption that all the weapons used in the Subcommittee's exercise are detonated at ground level, that is, with the fireball touching the surface of the earth, maximum local fallout would result.

Generally stated, in a surface burst, large quantities of earth are drawn into the fireball and become mixed with the fission products of the weapon. This mixture of earth and fission products is carried to high altitudes by a rising column of heated air. Upon cooling, this material gradually falls back to the earth. These particles, contaminated with radioactive products, are the fallout.

Local fallout is that which comes down in the general region of the earth in which the detonation occurred, that is, within several hundred miles, at most, and within a few days.

The local fallout pattern is usually irregular in shape but having the general outline of a long cigar with one end at the burst point. For a 10-megaton surface burst with 50 percent of its yield due to fission, there would be an area of about 2,500 square miles (extending about 150 miles downwind and having a maximum width of about 25 miles) within which all people exposed in the open without shelters would obtain a dose of at least 450 rem during the first 48 hours. The dose of 450 rem would occur on the edge of the fallout pattern. Inside of the 2,500 square miles the fallout radiation and doses would be greater near the center of the fallout pattern and at distances closer than 150 miles downwind from the burst. The fallout radiation would be less outside of the 2,500 square miles area at distances greater than 150 miles downwind or away from the center of the fallout pattern. Inside of the above fallout pattern for a single weapon there are areas with radiation intensities as high as 3,000 roentgens per hour up to 1 hour after the detonation.

(5) *Worldwide fallout.*—Worldwide fallout is produced by the fine particles which ascend high into the troposphere and stratosphere, are carried by the winds around the earth, and descend over a long period of time. Tropospheric fallout descends within about 1 month in a more or less banded region of the same general latitude of the detonation. Stratospheric fallout is more delayed, occurring within a few months to a few years.

Approximately 20 percent of the total fallout of the weapons used in the subcommittee's exercise would be of the worldwide type. Fifteen percent would be stratospheric and about 5 percent would be tropospheric.

SUMMARY OF EFFECTS FOR 1-MEGATON AND 10-MEGATON NUCLEAR WEAPONS

Blast, which is primarily a damaging agent to inanimate objects such as buildings, produces flying debris which is a hazard to man. The cratering effects result in the destruction of even deep underground structures.

Thermal radiation damages both humans and combustible structures and materials.

Nuclear radiation, including both the initial and residual fallout are primarily hazards to man and animals.

The distances and areas covered by various effects are contained in the following table:

TABLE IV–1.—*Summary of effects of the assumed nuclear weapons 1 to 10 megatons*

	1 megaton	10 megatons
A. Inanimate objects:		
1. Crater (dry soil)	Radius, 650 feet; depth, 140 feet.	Radius, 1,250 feet; depth, 240 feet.
2. Brick apartment houses collapse.	Radius, 3 miles	Radius, 7 miles.
3. Ignition of light kindling materials.	Radius, 9 miles	Radius, 25 miles.
B. Man:		
1. Blast injury (flying debris)	Radius, 3 miles; area, 28 square miles.	Radius, 7 miles; area, 150 square miles.
2. 2d degree burns on bare skin	Radius, 9 miles; area, 250 square miles.	Radius, 25 miles; area, 2,000 square miles.
3. Initial nuclear radiation (700 rem).	Radius, 1.5 miles; area, 7 square miles.	Radius, 2 miles; area, 12.5 square miles.
4. Fallout, 15-knot winds (450 rem in 48 hours, no shielding).	40 miles downwind; 5 miles crosswind; area, 200 square miles.	150 miles downwind; 25 miles crosswind; area, 2,500 square miles.

V. RADIOACTIVE FALLOUT PATTERNS, PHYSICAL DAMAGE AND CASUALTIES IN THE UNITED STATES

Based on the specific attack assumptions developed by the subcommittee, the Office of Civil and Defense Mobilization prepared a damage assessment with respect to blast, thermal, and fallout effects on dwellings and people during the period of 90 days following the attack.

While the primary effects of nuclear explosions may claim the greatest number of victims, the threat of persisting radioactivity poses the greatest hazard to survivors. It was for this reason that the subcommittee devoted much of its investigation to the problem of radioactive fallout.

FALLOUT PATTERNS

The fallout situation plotted by the OCDM is depicted on the maps reproduced in figures V–1, 2, 3, 4 and 5 showing conditions at the postattack time periods of 1 hour, 7 hours, 2 days, 2 weeks, and 3 months.

These maps show the progression of fallout across the United States during the first 2 days postattack and then indicate its subsequent retreat as radiation decay begins to predominate over further deposition of fallout. At 1 hour post-attack less than 10 percent of the country is affected by fallout but the dose rates are very high, exceeding 3,000 roentgens per hour in some areas. By 7 hours,

approximately 30 percent of the national land area is covered by fallout intensities exceeding 1 roentgen per hour; and after 2 days 46 percent of the national land area is affected by intensities ranging from one-tenth roentgen per hour to greater than 30 roentgens per hour. Two weeks after the attack, as a result of radiation decay, only 15 percent of the national land area has fallout intensities exceeding one-tenth roentgen per hour and after 3 months only 5.8 percent of the area is affected by this intensity.

Two important factors concerning these fallout data require special attention. First, it is important to distinguish between the radiation dose rates, indicated here, and total dose accumulation, that is, the total dose which an unsheltered person would receive in a given period of time at a specified geographic location. Secondly, the stated dose rates as computed by OCDM are based on the $t^{-1.2}$ decay principle, which is at variance with later findings of the U.S. Naval Radiological Defense Laboratory.

The $t^{-1.2}$ rule, which long has been accepted by the scientific community, simply means that in general the radiation intensity existing 1 hour after a nuclear explosion will decline by a factor of 10 for every sevenfold increase in time. That is, if the 1-hour postattack dose rate is 3,000 roentgens per hour, 7 hours after the explosion the rate will be 300 roentgens per hour. Forty-nine (7×7) hours after the explosion the rate will be 30 roentgens per hour. At 343 (7×7×7) hours after the explosion the rate will be 3 roentgens per hour.

Although the NRDL data suggest a slower initial decline in dose rate, they indicate a more rapid decline after 1 year. However, whether one uses the $t^{-1.2}$ rule or the NRDL data, the requirement for population shielding in the period immediately following a possible attack remains substantially the same. A fuller discussion of the NRDL data is contained in a later section of this report, beginning at p. 28.

With respect to total radiation doses, data presented at the hearings indicate that in some sections of the country the hypothetical attack would have produced accumulated doses exceeding 12,000 roentgens during the first 3 months. As pointed out by OCDM witnesses, this means that persons who survived the initial impact of the attack in such highly contaminated areas would have to be moved to safer locations.

It should be noted that the official OCDM position with respect to the radiation hazards of a possible nuclear war is that fallout shelters should be prepared for the entire population of the United States. Although the fallout projections in figures V–1, 2, 3, 4, and 5 show some areas of the country to be free of fallout and others to be contaminated with extremely low radiation intensities, such areas cannot be accurately predicted in advance of a possible attack because of variables in such factors as target selection, aiming errors, weapon sizes and weather conditions.

DAMAGE SUSTAINED BY DWELLINGS

The blast damage sustained by dwellings in the United States as a result of the hypothetical attack is indicated in table V–1. Eleven million eight hundred thousand dwellings, or more than one-fourth of

the dwellings in the United States, suffered damage to the extent that they would not be salvageable.

An additional 8.1 million dwellings suffered moderate damage and would have to be evacuated for major repairs; and 1.5 million dwellings suffered light damage. This totaled 21.4 million dwellings damaged.

TABLE V-1.—*Effects on dwelling*

	Units
Blast effects:	
Severe damage	11,800,000
Moderate damage	8,100,000
Light damage	1,500,000
Fallout effects:	
Greater than—	
3,000 roentgens per hour	500,000
1,000 to 3,000 roentgens per hour	2,100,000
100 to 1,000 roentgens per hour	10,400,000
Less than 100 roentgens per hour	11,700,000

Outside the areas of blast and thermal damage, some 2,600,000 dwellings sustained radiation intensities exceeding 1,000 roentgens per hour and would have to be evacuated and abandoned for periods extending up to several months. An additional 10.4 million dwellings sustained radiation intensities varying between 100 and 1,000 roentgens per hour. With major decontamination effort most of these 10.4 million homes could be recovered by 60 days postattack.

In summary, almost 50 percent of existing dwellings in the United States were either severely damaged or contaminated by fallout to the extent that they would not be usable for at least several months postattack.

CASUALTIES

Based on 1950 census data, it was calculated that 19.7 million persons would have been killed the first day; 22.2 million additional persons would have been so badly injured that they would subsequently die of their injuries. There would have been approximately 17.2 million additional persons injured who could be expected to recover from the injuries received. Of those killed, 25 percent would have died from fallout and approximately 75 percent would have died as a result of blast and thermal injuries, combined to a great extent with radiation injuries.

Of the surviving injured, approximately 6.3 million would have blast and thermal injuries and 10.9 million would have radiation injuries.

Due to the population increase of approximately one-sixth since the 1950 census, it was noted that these casualty estimates might be increased by approximately 16 percent on a national basis. If this increase is included, the above casualty estimates would be changed to 22.8 million persons killed on the first day; 25.7 million additional persons fatally injured; and 19.9 million persons nonfatally injured. This increase, however, cannot be accurately applied to individual area estimates.

The charts which follow (tables V-2 and 3), again based on 1950 census data, show the numbers of fatalities and surviving injured by OCDM regional areas, by States, and within the 71 population and industrial centers included as targets in the hypothetical attack. It will be noted that of the total 19.7 million people killed on the first day, approximately 11.4 million were in the 12 largest metropolitan areas

in the United States. The New York City area sustained the greatest loss with over 6 million dead or dying and over 2 million surviving injured. Seventy-five percent of the persons living in the Boston area were killed, and in Los Angeles fatalities amounted to 65 percent. In Chicago fatalities amounted to only 18 percent of the population, while in Baltimore they approached 80 percent.

With respect to radiation casualties, it is important to note that the OCDM estimates assumed that the population would take advantage of the fallout protection provided by existing buildings. The protection factors used in these estimates ranged from a reduction to one-half for those afforded the worst protection to a reduction to one two-hundredth for those afforded the best protection. It is possible that some groups of the population would have less protection than one-half reduction and some would have better protection than one two-hundredth reduction, but in the opinion of the OCDM the differences in the national totals would not be significant.

A factor of considerable significance, however, is that the above radiation casualty estimates are based on the $t^{-1.2}$ radiation decay rule, rather than on the most recent decay data developed by the Naval Radiological Defense Laboratory. Estimates based on the NRDL data, and subsequently presented by the OCDM at the request of Chairman Holifield, indicate that there would have been 5.1 million more fallout fatalities and 1.6 million more nonfatal fallout casualties than the $t^{-1.2}$ assumption indicated. The totals would then be 53.6 million fatalities and 20.5 million nonfatally injured.

It should also be noted in this connection that an upward revision of the estimated LD 50 rate (the radiation dose at which one-half those exposed would be expected to die), as suggested by some witnesses, would reduce the overall casualty estimates to some extent.

The subcommittee believes it is also important to note that almost 100 million of our people (56 percent of the population) would have survived this hypothetical attack without suffering blast, thermal, or serious fallout effects. Further, as pointed out by the OCDM, more than 96 million people in the United States do not live in or near likely target areas and could be expected to survive a nuclear attack merely through the provision of fallout shelter and a 2 weeks' supply of food and water.

The subcommittee recognizes that the long-range problems of a post-nuclear-war period would be extremely difficult, but this phase of recovery and rehabilitation was not within the scope of these particular hearings. A study of this aspect of national survival might well be explored by an appropriate committee of Congress.

TABLE V-2.—*Effects on individual metropolitan areas*

[In thousands]

Target area and weapons	Number of people in attacked areas [1]	Number killed 1st day	Number fatally injured	Number surviving injured
Two 10-megaton weapons each:				
Boston	2,875	1,052	1,084	467
Chicago	5,498	545	447	648
Detroit	3,017	820	593	557
Los Angeles	4,367	698	2,136	814
New York City	12,904	3,464	2,634	2,278
Philadelphia	3,671	1,309	989	777
Subtotal	32,332	7,888	7,883	5,541
One 10- and one 8-megaton weapon each:				
Baltimore	1,338	591	466	174
Cleveland	1,466	394	298	316
Pittsburgh	2,214	597	659	43
St. Louis	1,292	563	370	161
San Francisco	2,241	734	769	301
Washington, D.C	1,465	579	433	228
Subtotal	10,016	3,458	2,995	1,223
One 10-megaton weapon each:				
Atlanta	672	155	206	160
Buffalo	1,089	253	140	158
Cincinnati	904	461	261	93
Dallas	614	130	314	124
Houston	807	81	57	114
Kansas City	814	265	230	144
Milwaukee	872	151	112	189
Minneapolis	1,117	201	92	97
New Orleans	685	319	226	74
Portland	705	156	103	131
Providence	682	210	263	144
Seattle	732	168	99	126
Subtotal	9,693	2,550	2,103	1,554
One 8-megaton weapon each:				
Albany	514	69	51	63
Birmingham	559	159	137	86
Columbus	504	245	134	54
Dayton	458	200	119	58
Denver	564	138	144	118
Indianapolis	552	137	88	109
Louisville	577	264	156	59
Memphis	482	76	51	97
Norfolk	446	180	117	59
Rochester	488	212	107	59
San Diego	557	58	202	126
Youngstown	529	121	189	76
Subtotal	6,230	1,859	1,495	964
One 3- and one 2-megaton weapon each:				
Akron	410	162	104	66
Allentown	436	45	79	117
Fort Worth	361	73	189	74
Hartford (New Britain)	539	124	110	119
Springfield-Holyoke	456	157	100	72
Toledo	396	107	74	75
Wilkes-Barre	393	51	48	63
Subtotal	2,991	719	704	586
One 3-megaton weapon each:				
Bridgeport	504	105	84	54
Canton	283	84	59	42
Chattanooga	246	85	77	29
Davenport	234	73	53	53
Erie	219	54	42	42
Flint	271	77	46	39
Grand Rapids	287	124	66	21
Knoxville	337	112	106	38
Lancaster	235	54	51	49
New Haven (Waterbury)	546	192	138	95
Peoria	250	84	54	28
Reading	256	72	66	60
South Bend	205	84	53	34

See footnote at end of table, p. 20.

TABLE V-2.—*Effects on individual metropolitan areas*—Continued

[In thousands]

Target area and weapons	Number of people in attacked areas [1]	Number killed 1st day	Number fatally injured	Number surviving injured
One 3-megaton weapon each—Continued				
Syracuse	342	89	68	73
Trenton	230	41	80	97
Utica-Rome	284	107	60	2
Wheeling	355	59	58	46
Wichita	222	78	75	38
Wilmington	269	77	76	67
Worcester	547	128	151	97
Subtotal	6,122	1,779	1,463	1,004
One 1-megaton weapon each:				
Binghamton	185	58	32	17
Evansville	161	60	34	23
Fort Wayne	184	69	41	23
Greensboro	191	28	19	32
New Britain (included with Hartford).				
Rockford	152	42	25	25
Waterbury (included with New Haven).				
York	203	46	31	17
Subtotal	1,076	303	182	137
City target area total	68,460	18,556	16,825	11,009
Nontarget area total	82,239	1,095	5,354	6,182
Grand total	150,699	19,651	22,179	17,191

[1] 1950 population figures.

TABLE V-3.—*Effects of attack on individual States*

[In thousands]

State and region [1]	Number people in State [2]	Number killed 1st day	Number fatally injured	Number surviving injured
Region 1:				
Connecticut	2,007	455	443	380
Maine	914	43	67	77
Massachusetts	4,691	1,347	1,501	878
New Hampshire	533	30	48	41
New Jersey	4,837	291	875	1,209
New York	14,830	4,067	2,702	2,123
Rhode Island	792	210	294	192
Vermont	378	----------	18	24
Total	28,982	6,443	5,948	4,924
Region 2:				
Delaware	318	78	87	67
District of Columbia	803	440	257	75
Kentucky	2,945	344	246	149
Maryland	2,344	698	648	330
Ohio	7,948	1,657	1,421	1,069
Pennsylvania	10,495	2,164	2,134	1,723
Virginia	3,319	239	231	233
West Virginia	2,006	100	213	158
Total	30,178	5,720	5,237	3,824
Region 3:				
Alabama	3,062	169	263	248
Florida	2,771	90	271	245
Georgia	3,444	120	369	417
Mississippi	2,179	31	147	160
North Carolina	4,062	29	300	389
South Carolina	2,117	28	133	134
Tennessee	3,292	272	292	257
Total	20,927	739	1,775	1,850

See footnotes at end of table, p. 21.

TABLE V-3.—*Effects of attack on individual States*—Continued

[In thousands]

State and region [1]	Number people in State [2]	Number killed 1st day	Number fatally injured	Number surviving injured
Region 4:				
Illinois	8,714	726	686	878
Indiana	3,935	370	371	388
Michigan	6,371	1,020	738	694
Missouri	3,953	801	594	321
Wisconsin	3,435	172	148	258
Total	26,408	3,089	2,537	2,539
Region 5:				
Arkansas	1,910	4	59	43
Louisiana	2,683	420	443	291
New Mexico	681	92	108	75
Oklahoma	2,234	37	166	172
Texas	7,710	618	1,318	858
Total	15,218	1,171	2,094	1,439
Region 6:				
Colorado	1,326	167	205	174
Iowa	2,621	88	66	58
Kansas	1,905	113	155	146
Minnesota	2,983	15	17	50
Nebraska	1,325	43	47	84
North Dakota	620	5	5	12
South Dakota	653	1	3	10
Wyoming	291	32	16	----------
Total	11,724	464	514	534
Region 7:				
Arizona	750	58	90	82
California	10,585	1,547	3,598	1,500
Nevada	160	----------	23	28
Utah	689	9	16	27
Total	12,184	1,614	3,727	1,637
Region 8:				
Idaho	588	----------	10	20
Montana	591	2	7	16
Oregon	1,521	156	99	114
Washington	2,378	253	231	294
Total	5,078	411	347	444
Grand total	150,699	19,651	22,179	17,191

[1] OCDM regions.
[2] 1950 population figures.

VI. CHARACTERISTICS OF RADIOACTIVE FALLOUT

Data concerning the characteristics of radioactive fallout were presented to the subcommittee in three general categories: worldwide fallout; basic properties and effects of fallout; and factors modifying the behavior of radioactive deposits.

WORLDWIDE FALLOUT

The charts appearing in figures VI-1 and 2 were prepared by Dr. Lester Machta of the U.S. Weather Bureau to illustrate the worldwide strontium 90 fallout and the total strontium 90 fallout on the United States which would result from the subcommittee's attack assumptions. While these charts depict only strontium 90, the results can also be applied roughly to cesium 137.[9]

[9] For purposes of simplification, short-lived radionuclides were not included in this presentation. There is information suggesting that these short-lived radionuclides could contribute an appreciable portion of the worldwide fallout dose.

Production of radioactive debris

The total megatonnage of weapons detonated in the subcommittee's attack assumptions was approximately 4,000 (1,500 on the United States and 2,500 elsewhere in the Northern Hemisphere). Fifty percent of the energy from each weapon was assumed to be derived from fission, for a total of 2,000 megatons of weapon yield energy equivalent of fission products. Each megaton of fission energy creates approximately 100,000 curies of strontium 90. Thus, the 2,000-megaton energy equivalent of fission produced 200 million curies of strontium 90. These curies are divided roughly as follows: 80 percent is deposited in local fallout, 15 percent in stratospheric fallout, and 5 percent in tropospheric fallout. Approximately 20 percent of the 200 million curies go into worldwide dispersal.[10]

In the United States, the local fallout deposition was calculated by the OCDM based on the idealized model contained in "The Effects of Nuclear Weapons" handbook. Since estimates of the total (local plus worldwide) as well as the worldwide strontium 90 fallout are desired for the United States, it is necessary to convert the external dose to the strontium 90 which is associated with the gamma emitting fission products. Based on "The Effects of Nuclear Weapons" handbook, and allowing a small correction for shielding of particles in the ground, it is assumed that 1 roentgen per hour at 1 hour is equivalent to 100 millicuries (i.e., 0.1 curie) of strontium 90 per square mile in local fallout. This type of estimating is, of course, very rough.

Distribution of the worldwide fallout

The tropospheric strontium 90 is carried rapidly around the world in a generally west-to-east direction. It spreads in a north-south direction slowly so that the peak fallout is roughly in the latitude of the war area. The stratospheric fallout is deposited entirely in the Northern Hemisphere, peaked at about 45° N. and tapering off toward the Equator and North Pole. Both tropospheric and stratospheric fallout are brought down mainly with falling rain or snow; most of the tropospheric within about a month after the war and the stratospheric within a few months to a few years. The observed rainfall for the first month after mid-October 1958 was used in estimating the tropospheric fallout, and the average annual rainfall, weighted slightly to give spring rains a greater effectiveness, was the basis for the stratospheric deposition pattern.

The peak accumulation of strontium-90 in most places will probably occur in about 3 to 5 years after the attack. During this period about 10 percent of the strontium 90 produced will have decayed. Within the areas of heaviest local fallout, where levels are greater than about 10,000 millicuries of strontium 90 per square mile (see fig. VI–2) radioactive decay will be greater than the added tropospheric and stratospheric fallout and the peak values will occur at the time of the attack. Beyond 3 to 5 years following the war, the changes in deposited strontium 90 fallout are principally due to radioactive decay; 2½ percent of the remaining strontium 90 is lost each year.

Figure VI–1 is a polar stereographic projection of the Northern Hemisphere, showing isolines of worldwide strontium 90 deposition

[10] The above figures are based on the difficult-to-substantiate assumption of "no fractionation" of the radioactive debris. That is, the percentages given above are assumed to apply equally to every fission product, specifically strontium 90. See p. 24.

in millicuries per square mile. This map does not show the local fallout on the United States or other countries. The highest line appearing on the map is 1,400 millicuries per square mile in the western North Atlantic. The more intense fallout here is due to heavy rainfall and to the proximity to the numerous bombs dropped on the northeastern part of the United States.

The arid Southwest United States and North Africa show smaller than average fallout values. In round terms, the entire north temperate zone will receive about 1,000 millicuries per square mile from worldwide fallout. This, for reference, can be compared with about 75 millicuries per square mile as the highest observed fallout value in the United States up to the fall of 1958.

It should be noted that the worldwide pattern is not very sensitive to where in the north temperate zone the attack took place. Thus, if all 4,000 megatons were dropped on the United States the condition over Europe would be very similar to that depicted here.

Figure VI–2 is a map of strontium 90 fallout on the United States including both local and worldwide fallout. The levels of strontium-90 deposition resulting from the local fallout far exceed the worldwide fallout except at the edges of the local fallout patterns. Thus, many of the strontium 90 isolines (based on the total deposit) are similar to the gamma dose rate isolines given by OCDM.

The innermost isoline within which there is heavy shading contains over 300,000 millicuries of strontium 90, per square mile, or over 300 times the typical worldwide fallout. However, not all of this heavy deposit will be biologically available under conditions of the attack due to the low solubility (less than 3 percent) of material in the local deposit.

It would take over 250 years for the strontium 90 level within the 300,000 millicuries per square mile line, the heavy shaded area, to be reduced to 1,000 millicuries per square mile, for example, if only decay were considered.

It has been calculated that as a result of all nuclear weapons testing to date by the United States, United Kingdom, and the U.S.S.R., the concentration of strontium 90 in the bone of man could ultimately rise in the Northern Hemisphere to a maximum average of about 5–10 micromicrocuries (millionths of a millionth) per gram of bone calcium. Since this is a result of about 90 megatons of fission yield, for the 2,000 megatons of fission yield assumed in this hypothetical attack, one can multiply the testing value by about 20 to get the wartime effect. The result is about 100–200 micromicrocuries of strontium 90 per gram of bone calcium. This is higher than the maximum permissible concentration of 67 strontium units recommended for the population as a whole on a peacetime standard, but is considerably lower than the 2,000 strontium units recommended as the maximum permissible occupational dose under controlled conditions. Similarly, the Northern Hemosphere genetic dose due to past testing is expected to be at most 0.05 roentgen, over a 30-year period, and there would be about 1 roentgen in the assumed war. This is less than the natural background genetic dose of 3 roentgens per 30 years. The worldwide fallout hazard thus would not be very important in terms of the survival of the countries not attacked or not in the downwind local fallout patterns. However, the long term

genetic and somatic hazards to the populations of these countries have to be recognized.

Cesium 137 and carbon 14

The isolines on the maps may be readily, but only approximately, converted from strontium 90 to cesium 137 by simply multiplying by 2. About twice as many cesium 137 atoms as strontium 90 atoms are formed by the nuclear explosives. The half-life of the two substances are almost identical and it is assumed that they do not fractionate with respect to one another, that is, there is no tendency for more of one than the other to be deposited in local or worldwide fallout. The biological availability of cesium 137 does, however, differ from that of strontium 90.

The radioactive carbon 14, which presents a genetic hazard following a nuclear war, is present in the form of carbon dioxide when in the atmosphere. The natural carbon dioxide of the air also contains cosmic ray carbon 14 radioactivity in small amounts from which it is possible to compute its very small dosage of ionizing radiation to man. If the level of carbon 14 is raised, the dosage to man will also increase.

There is considerable uncertainty as to the amount of carbon 14 that would be created during the hypothetical situation set forth by the subcommittee. For purposes of this exercise, however, it may be noted that large quantities of carbon 14 would be added to the atmosphere, mainly the stratosphere.[11] Within a few years after the attack, the added carbon 14 would be mixed with the troposphere and the biosphere. At this time, before mixing with the Southern Hemisphere and the surface layers of the oceans is complete, the carbon 14 in the ground level Northern Hemisphere air may rise to about 20 times natural cosmic ray carbon 14 background. After several years to tens of years later, mainly as a result of mixing with the surface layers of the oceans, the excess carbon 14 will be halved. Then gradually over a period of several hundreds of years mixing with the large carbon reservoir of the deep oceans the weapon-created carbon 14 in the lower atmosphere and biosphere will be reduced to less than 50 percent of natural background. Continued radioactive decay will very slowly decrease the excess carbon 14 after mixing is complete. The half-life of carbon 14 is 5,600 years, so the rate of decay is indeed slow.

BASIC PROPERTIES OF RADIOACTIVE FALLOUT

General description of the mechanisms of formation

When the nucleus of a heavy atom like uranium is split by nuclear fission, or the nuclei of two light atoms such as hydrogen are combined by nuclear fusion, a part of the mass of these materials is lost in the process and is converted into energy. This process gives rise to a large number of neutrons, and gamma rays, as well as the almost instantaneous creation of great quantities of heat in the immediate vicinity of the nuclear explosion products. The neutrons, traveling outward from the explosion with almost the speed of light, can react with materials in the environment and induce radioactivity into these materials by a process very similar to that which is used in the manufacture of radioisotopes in nuclear reactors. Neutrons are

[11] Testimony based on weapons test experience indicates that approximately 8×10^{29} (800 billion billion billion) carbon 14 atoms would be added.

generated both by the fission process and the fusion process. The quantities of radioactive isotopes induced in the environment are about the same regardless of the design of the weapon. With weapon yields of the order of megatons used in the subcommittee's hypothetical attack, the radioactivity produced by this activation process may be quite significant.

There are over 40 ways in which a heavy nucleus such as uranium or plutonium can divide in the process of nuclear fission, leading to the production of 80 to 90 primary radioactive products. These products in turn decay very rapidly at the start so that the fission mixture soon consists of some 200 radioactive species. It is the gamma radiation emitted in the process of radioactive decay of these fission products that is of most concern in local fallout.

During the first few thousandths of a second of the explosion, all of the material in the weapon, including the radioactive explosion products, and the material in the immediate vicinity of the weapon in the environment are completely vaporized. This high temperature gives rise to the fireball which expands rapidly, heating the material in the environment as it expands. At the same time the fireball starts to rise. Therefore, the initial part of the explosion creates a mixture of gaseous material, melted material, and perhaps some partially melted environmental material.

As the fireball cools, the melted material begins to solidify and the gaseous material begins to condense. Materials with very high melting or boiling points such as iron, of course, condense first. Similarly, the radioactive elements with similar boiling points will tend to condense at the same time leaving the more gaseous components behind. Therefore, the radioactive species are incorporated into particles in the fireball in a nonuniform manner. Also, as the fireball rises violent winds are created, which suck into the hot fireball large quantities of soil. Small, molten particles tend to condense onto this material. This debris from the immediate environment, whether it be soil or water, becomes thoroughly mixed with the radioactive products from the explosion very much like flavoring is mixed into a cake batter. It is these heavy dirt particles, "flavored" with small quantities of radioactive debris, which return rapidly to the earth and are called local fallout.

Properties of fallout material from a land-surface detonation

A summary of the gross physical properties of the fallout material collected at two distances, one 8 miles downwind from the point of detonation and the other 60 miles downwind from the point of detonation is shown in table VI–1. All direct measurements of the physical properties of radioactive fallout material have been made in connection with the weapon-test program and from this point of view the information is artificial. The test fallout debris from detonations on a tower are, of course, the result of the vaporization of a large amount of either iron or aluminum used in the construction of the test towers. Only low-yield weapons have been detonated on the ground at Nevada, where the soil is coarse and sandy. All large yield land surface detonations conducted by the United States have been detonated on the coral atolls in the South Pacific. Therefore, this environmental material has the chemical composition of the coral. Just what the properties of the fallout material would be for a deto-

nation on clay or loam, or in a metropolitan industrial complex such as a city is not known.

From table VI–1 it can be seen that the particle size of the debris descending at a distance of 8 miles from the point of detonation is expected to be relatively large, whereas the average size of the material depositing at 60 miles downwind is relatively smaller. By comparison, the material drawn into the stratosphere and which contributes to worldwide fallout probably has a particle size of the order of 0.02 millimeter. Attention is called to the fact that the distribution of radioactivity within the fallout particles themselves is quite irregular and that the bulk of the radioactivity associated with these particles is related to the particle size. It is significant that the largest particles contain the most radioactivity.

TABLE VI–1.—*Physical properties of land-surface burst fallout*

Properties of particles [1]	~8-mile downwind [2]	~60-mile downwind
General description	Melted, glassy solid containing air bubbles and mineral grains	
Range of diameters	~0.075 to 1.5 millimeters	~0.050 to 0.30 millimeter.
Predominant size	~0.35 millimeter in diameter	~0.10 millimeter in diameter.
Color	Transparent to opaque, pale green or yellow to brown or black	
Shape	Spherical to irregular	
Specific gravity	~1.4 to 2.6 gm/cm^3	
Distribution of radioactivity	Irregularly throughout	
Relation of radioactivity to size	$A \alpha D_{max}^{\sim 3}$ but with the range of A increasing with D_{max}	

[1] Based on properties of particles from kiloton bursts on silicate sand; all other information derived from megaton bursts on coral sand.
[2] ~: Approximately.

The chemical and radiochemical properties of the fallout material from a land-surface burst is summarized in the printed hearings. Less than 3 percent of the radioactivity associated with these large particles is soluble by leaching with water for several days. This implies that the radioactivity associated with these particles is not available for incorporation into plants and animals, at least for short periods of exposure to the elements. There is a significant list of radioactive isotopes which can be induced, either by neutron activation of materials within the weapon, or by activation of materials within the immediate environment, which under various conditions can contribute quite significantly to the quantity of gamma radiation associated with this fallout material. Testimony presented at the hearings indicated that the presence of such induced activities should be recognized and their presence ignored only after positive evaluation has indicated that it may be proper to do so.

Finally, it may be noted that under the conditions suggested in this exercise, as much as 90 to 95 percent of the fission products generated by the explosion could be found in the close-in or local fallout. This, of course, includes virtually all of the important gamma-emitting radioactive isotopes. However, due to the mechanism of formation as indicated in the preceding section, it is noted that only around 50 percent or less of the important isotopes strontium 90 and cesium 137 are found in the local fallout. Due to the mechanism of formation this fraction is highly variable but the general implication is that due to fractionation the gamma-emitting radioactive materials

which can create a radiation threat from fallout under conditions of nuclear war are preferentially pulled down in the local fallout, whereas the long-lived isotopes which are significant in worldwide fallout and as possible sources of difficulty under conditions of the testing of nuclear weapons in times of peace, are preferentially distributed through the worldwide fallout. These fractions are also very highly variable and are quite sensitive to the precise conditions of the detonation. For surface bursts the standard estimate from the weapon-test program is to assume 80 percent of the total weapon debris deposits as close-in fallout, 15 percent appears as stratospheric fallout, and 5 percent remains in the troposphere.

The ability of gamma radiation to penetrate through solid materials such as would be found in the walls of structures is directly related to the energy of the radiation. Naturally, with a mixture as diverse as that of the fission mixture, the range of the energies from the gamma radiation is quite wide. It varies from as low as 0.01 Mev.[12] to as high as 2.5 Mev. It is, however, of considerable interest to see how the average energy of this complex mixture will change as a function of time. These data are shown in table VI–2.

TABLE VI–2.—*Radiation characteristics of land-surface burst fallout*

[In million electron volts]

Characteristics	8-mile downwind	60-mile downwind
Ionization decay rate: Average energy:		
1 hour	------------	1.0
2 hours	------------	0.95
½ day	------------	.60
1 day	------------	.40
1 week	0.25	.35
1 month	.45	.65
2 months	.55	.65
1 year	------------	.55

Arrival and deposition characteristics

The principal arrival and deposition characteristics of a land surface detonation are summarized in table VI–3. At a distance of 8 miles from a 5-megaton detonation, the first fallout material can be expected to start arriving about 15 minutes after the detonation, to reach its peak at about 1.5 hours, and to be essentially completed in 6 hours. The total mass of dirt would amount to several tons per square mile at this distance, and the major portion would carry no radioactive material at all. However, a portion would carry radioactive debris, and the gamma radiation dose rate would start increasing at the time the first material arrived.

The gamma radiation rate would continue to increase for about 2½ hours, at which time the rate of radioactive decay would become equal to the rate of replenishment and the dose rate would level off and start decreasing by the end of 4 hours. After 6 hours, when the fallout ceased, the dose rate would diminish with a rate characteristic of the mixture of radioactive species that was present at that point.

At a distance of 60 miles, the time sequence would be very much the same, but slower. Fallout material would start arriving at about 7 hours after the detonation. It would reach a peak at 13 to 14

[12] Mev.: A unit of energy expressed in millions of electron volts.

hours and would be over in about 16 hours. The gamma radiation dose rate would reach a peak value at 10 to 14 hours after the detonation.

The total mass of material at either distance could amount to as much as 100 tons per square mile or more and the radiation intensities at either locality could be that associated with 1,000 roentgens per hour (measured at 1 hour after detonation). However, people at the closer location could receive about 6,000 roentgens more actual dose due to the 6- to 7-hour difference in the arrival time of the fallout.

TABLE VI-3.—*Arrival and deposition characteristic of land-surface burst fallout*

Characteristics	~6-mile downwind	~60-mile downwind
Time of arrival	~0.25 hour since detonation	~7 hours since detonation.
Time of peak	~1.5 hours since detonation	~13.5 hours since detonation.
Time of cessation	~6 hours since detonation	~16 hours since detonation.

Deviations with other detonation conditions

The information summarized so far is what would be expected from nuclear weapons detonated on the land surface as prescribed for this exercise. However, other detonation conditions which might be encountered in an actual attack would lead to different relations among these effects. The most important of these are summarized as follows:

1. An airburst produces little to no local fallout. The weapon debris condenses in highly soluble (50 percent or more), very small particles (less than 1 micron). The effective ranges of the blast effect, particularly at moderate damage levels, and thermal radiation become more important than the immediate nuclear radiation as the height of detonation is increased.

2. A detonation under sea water results in the formation of water and concentrated salt solution drops which, on drying, are more difficult to remove than dry dirt from a land-surface detonation. About 50 percent or more of the radioactive material is soluble and available for incorporation into food. Also, the water, with its lower boiling point, causes much less fractionation of the mixture of fission products, leading to less distortion of the radioactive decay characteristics.

Dose rate to total dose relations

Testimony presented at the hearings indicated that the actual release of gamma radiation energy from the fission products differs significantly from that represented by the $t^{-1.2}$ rule and other information given in the official Government publication "The Effects of Nuclear Weapons." Because of its significance to the estimates used in connection with these hearings, this point will be discussed in some detail.

From data in "The Effects of Nuclear Weapons," if the unfractionated fission products created from the detonation of 1-kiloton equivalent of nuclear explosion are deposited uniformly over 1 square mile, the contamination density (fission product density) will be equivalent to 300 gamma megacuries at 1 hour after the detonation. The corresponding gamma radiation emission rate [13] can be converted to the gamma radiation dose rate on the basis that the average energy

[13] The gamma emission rate describes the flux of nuclear radiation being emitted by a source. The gamma radiation dose rate describes the absorption of these radiations by the body.

of the gamma photons is 0.7 Mev. The gamma radiation dose rate at 1 hour after detonation for a contamination density of 1 kiloton per square mile can be related to the gamma radiation dose rate at any subsequent time by the relation, $R_t/R_1 = t^{-1.2}$. However, if the known facts concerning the formation and gamma emission properties of individual fission products are synthesized in tabular form, it is found that significant differences exist between these results and those computed by means of the standard formula. Data from one paper submitted to the subcommittee in connection with the earlier hearings on the effects of the weapon test program are reproduced in table VI–4. It can be seen from this table that the gamma radiation dose rate from the fission products of 1 kiloton nuclear yield per square mile at 1 hour is 2.7 times greater than that computed by the standard formula. Also, it can be seen that the total gamma radiation dose accumulated from 1 hour to 3 days is about 7,800 roentgens compared to 3,400 roentgens computed from the standard formula. Therefore, the magnitude of the gamma radiation threat from the fission products in fallout is greater than that calculated by means of the standard formula by a factor of about 2.

However, it can be seen that at 1 year the gamma radiation dose rate computed from the synthesis of the known fission products which could be present, is only about one-half that which is computed by the standard formula. At 3 years it is about one-seventh. This information is significant with regard to the estimation of the length of time an area might be denied to normal occupancy as the result of radioactive fallout.

TABLE VI–4.—*Comparison of gamma dose rates and integrated doses for uniform contamination level of 1 kiloton of fission products per square mile, contrasting the "Effects of Nuclear Weapons" handbook data ($t^{-1.2}$) with more recent computations developed by the U.S. Naval Radiological Defense Laboratory*

Time after detonation	Dose rate (roentgens per hour 3 feet above infinite plane)			Integrated dose from 1 hour (roentgens 3 feet above infinite plane)	
	Effects of nuclear weapons	NRDL–TR-247	Ratio NRDL/ENW	Effects of nuclear weapons	NRDL–TR-247
1 hour	1,260	3,360	2.7	0	0
2 hours	548	1,416	2.6	815	2,199
6 hours	147	317	2.2	1,898	4,706
12 hours	64	142	2.2	2,467	5,950
24 hours	28	55	2.0	2,964	7,012
48 hours	12.1	20.2	1.7	3,407	7,803
3 days	7.43	11.52	1.6	3,629	8,163
1 week	2.70	4.56	1.7	4,042	8,831
2 weeks	1.17	2.21	1.9	4,333	9,357
1 month	.483	.902	1.9	4,612	9,898
2 months	.204	.329	1.6	4,826	10,297
3 months	.126	.197	1.6	4,939	10,481
6 months	.0547	.0792	1.4	5,122	10,750
1 year	.0238	.0137	.58	5,273	10,911
2 years	.0104	.00185	.18	5,399	10,953
3 years	.00637	.00108	.17	5,475	10,965
5 years	3.45×10^{-3}	6.24×10^{-4}	.18	5,557	10,979
10 years	1.50×10^{-3}	4.80×10^{-4}	.32	5,657	11,002
20 years	6.52×10^{-4}	3.94×10^{-4}	.63	5,735	11,040
30 years	4.01×10^{-4}	3.26×10^{-4}	.81	5,782	11,071
60 years	1.75×10^{-4}	1.82×10^{-4}	1.04	5,847	11,136
100 years	9.46×10^{-5}	9.12×10^{-5}	.96	6,080	11,183

Since it is customary to convert measurements of roentgens per hour at 1 hour to a fission product density per square mile and from this conversion to compute the fraction of the fallout debris including such isotopes as strontium 90 and cesium 137 deposited in the close-in fallout region, it is clear that this information has a direct bearing on computations involving the distribution of fission product debris between close-in and worldwide fallout.

Additional information derived from testimony presented at the hearings, and considered by the technical panel covering the weapons effects problems, is the observation that nonfission product activities such as neptunium 239, uranium 237, uranium 240, sodium 24, manganese 56, and others, may also be present in the close-in fallout. Their gamma radiations may account for a substantial fraction of the open field roentgen dose particularly between the times of 8 hours and 1 week. These contributions, of course, would be in addition to the values already indicated in table VI–4 and would affect the conversion from gamma dose rate to strontium 90.

It was the consensus of the panel members that these differences from the standard formula would not seriously affect the validity of the relative estimates used for this exercise, but that the approximate nature of the estimates must be recognized when other applications are considered.

FACTORS MODIFYING BEHAVIOR OF RADIOACTIVE DEPOSITS

Effect of wind and weather

It was the consensus among all the experts testifying before the subcommittee that the weather plays a major role in determining the location and distribution of radioactive fallout. The weapon and environmental debris is carried by the wind far from the point of detonation as it settles through the atmosphere. Since the wind at different altitudes and in different sections of the country may differ considerably both as to direction and speed, the actual fallout contours encountered in reality differ markedly from the idealized cigar-shaped patterns normally used as the basis of estimating the fallout effects. Actual patterns measured in connection with the test program at the Nevada test site neither looked like a cigar nor had the smooth shape normally used. It was indicated that the irregularities are due to many factors, such as the complexities of the radioactivity distribution in the atomic cloud, the effect of water condensation within the mushroom, atmospheric turbulence, and the roughness of the ground on which the fallout takes place.

For purposes of estimates in connection with exercises such as the subcommittee's assumed attack situation, these irregularities were considered to be unimportant in evaluating casualties. However, in real fallout situations, the irregularities in the pattern complicate the work of evaluating the damage and forces one to rely almost entirely on measurements of radiation intensity at a given place rather than estimating them from nearby locations or from methods of prediction.

The principal differences that were indicated as affecting the location of the initial deposition on the ground may be summarized as follows:

(1) For a 5- to 10-megaton yield weapon detonated on the ground, the maximum fallout intensity may appear at a distance as great as 60 to 70 miles away from the original point of detonation.

(2) Not only is the deposition pattern irregular, but isolated "hot spots" appear at irregular locations both as to direction and distance in relation to the main axis of the deposition pattern. An illustrative example is shown in figure VI-1.

(3) One isolated "hot spot" with a radioactivity intensity about seven times greater than that in the immediate surroundings has been observed on the immediate downwind side of a mountain range. It was indicated that this, or the fact that some light rain was reported in the area at the time, may have contributed to the observation.

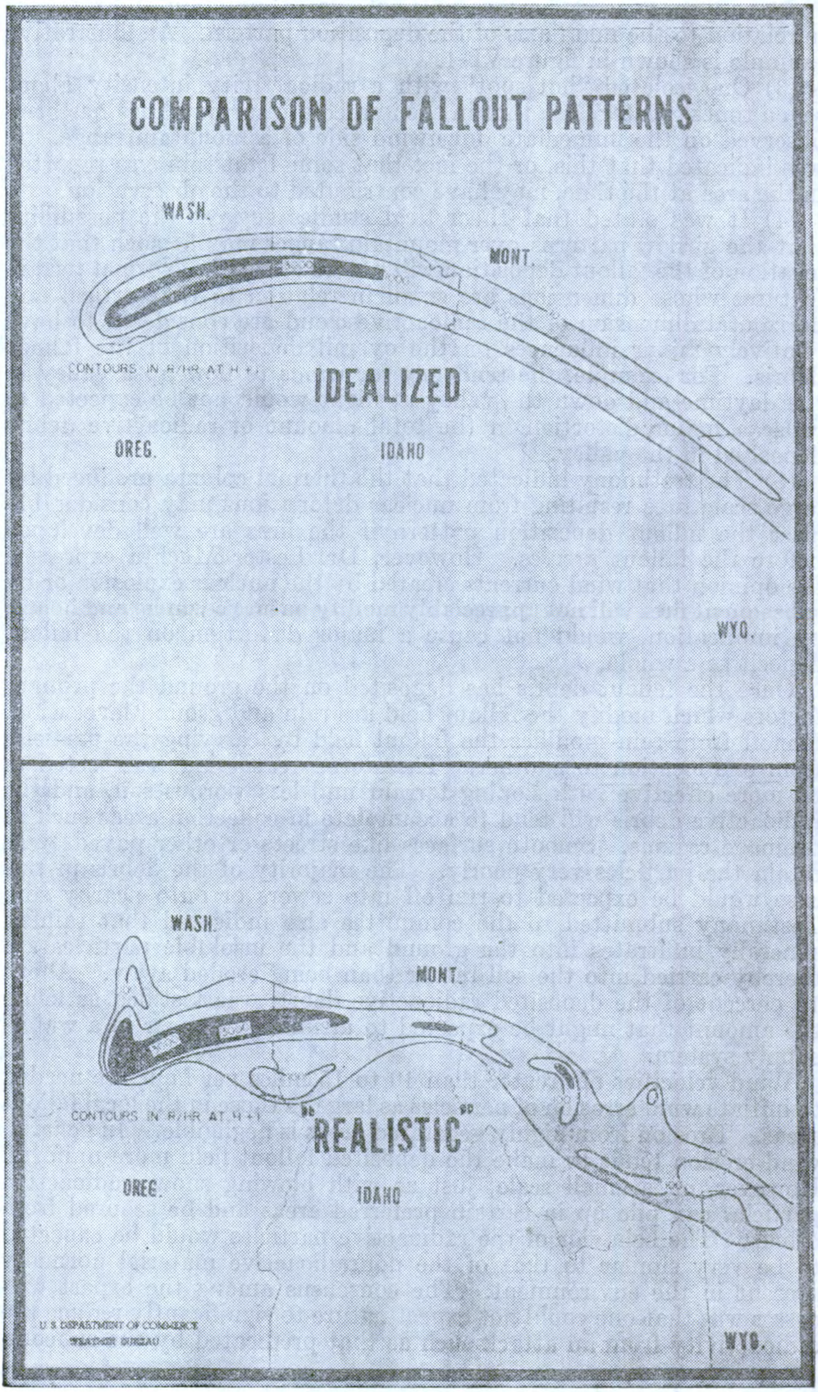
(4) It was stated that theoretical studies suggest the possibility that the airflow patterns over mountain ranges may be such that the location of the fallout deposition will not be affected. Normal terrain features whose dimensions are small in relation to the vertical and horizontal dimension of the radioactive cloud are considered to have relatively minor influences on the overall deposition of the fallout debris. For example, the tendency for winds to flow up a valley in the daytime and down the valley at night would not be expected to cause a major distortion in the total amount of radioactive debris deposited in the valley.

(5) The testimony indicated that the thermal column produced by large scale fires resulting from nuclear detonations may considerably alter the fallout deposition pattern if the fires are well developed before the fallout arrives. However, Dr. Lester Machta expressed the opinion that wind currents created by the nuclear explosion or by subsequent fires will not appreciably modify nature's winds, and hence, by implication, would not cause a major distortion on the fallout deposit as a whole.

Once the fallout debris has deposited on the ground the primary factors which modify the fallout field are rain and ground level wind. Runoff from rain modifies the fallout field by carrying the particles from one location to another. Therefore, weathering is expected to be more effective with sloping terrain and less porous soil, and the radioactive debris will tend to accumulate in collection areas such as drainage regions. Smooth surfaces like streets or other paved areas retain the particles very poorly. The majority of the debris in this case would be expected to run off into sewers or onto nearby soil. Testimony submitted to the committee also indicated that rainfall generally infiltrates into the ground and the insoluble particles are thereby carried into the soil rather than being eroded away. About 10 percent of the deposited radioactive debris was testified as being the amount that might be expected to ultimately appear in a water-supply system.

Wind velocities of greater than 10 to 15 miles per hour are needed to initiate wind errosion of particles as large as those in the local fallout areas. Erosion from highly vegetated areas is negligible. In general, wind erosion tends to make the deposited fallout field more uniform. However, on a small scale, just as with blowing snow, radioactive particles can pile up in certain preferred areas and be scoured from others. The behavior of the radioactive particles would be expected to be very similar to that of the nonradioactive material normally present in the environment. The consensus among the expert witnesses was that one could not expect nature to significantly reduce the radioactivity from an attack such as that predicated by the subcom-

FIGURE VI—1


COMPARISON OF FALLOUT PATTERNS
WASH.
MONT.
CONTOURS IN R/HR AT H+1
IDEALIZED
OREG.
IDAHO
WYO.
WASH.
MONT.
CONTOURS IN R/HR AT H+1
REALISTIC
OREG.
IDAHO
U S DEPARTMENT OF COMMERCE
WEATHER BUREAU
WYO.

mittee through the influence of natural weathering forces. The countermeasures will have to be man's own doing.

An analysis of the rainfall and wind patterns for the 2 weeks following the date of the hypothetical attack showed that the largest region of rainfall occurred in the eastern part of the United States from Ohio to Maine. In these areas although the rain was not heavy some benefit could be expected through washing the radioactive debris from the roofs and streets during the early part of the fallout period.

High winds occurred only in the northern Midwest region where the fallout deposition was sparse.

The effect of terrain and builtupness on the radiation

The previous section considered the influence of meteorology and terrain on the deposition of the fallout material. This material, which is the source of the nuclear radiation, is associated with the deposit. Therefore, the deposition information is related to a knowledge of where the maximum fallout threat may be expected to occur. However, the nuclear radiations from radioactive decay are also influenced by the environment. It is therefore of some interest to examine the effect of different orientations between the deposited material and the environment which may influence the subsequent behavior of the gamma radiation that is emitted.

According to testimony presented at the hearings, approximately one-half of the total dose to which a person standing in a flat area is exposed, originates within a radius of about 30 feet. From data already presented, it is clear that a person in such a position would not only be exposed to radiation from the material already deposited on a flat terrain, but would also be subjected to radiation originating from material in the cloud prior to the time the deposition was complete. The manner in which the radiation dose, hence, the radiation threat, might be distributed between these two conditions was not examined specifically in the course of the hearings. The following points with respect to the influence of the terrain on the radiation field resulting from material already deposited were brought out:

(1) The radiation intensity numbers used in connection with the standard scaling formulas are based on direct measurements of the fallout pattern on the ground. Therefore, they already incorporate the effects of induced activities that might be present, the effect of terrain at the point of measurement, and the effect due to the thickness of the deposit. These values would not be expected to agree precisely with those computed from the fission product density and the radioactivity characteristics of the fission products.

(2) A roughness of terrain ranging between that of a smooth concrete slab and that of a wooded hilly field decreased the radiation intensity at a standard height above the ground by approximately one-third of the radiation intensity computed by the "billiard table" reference condition. The degree of change was roughly proportional to the degree of roughness.

(3) An actual fallout deposit under experimental circumstances behaved as though it were uniformly mixed to a depth of about one inch in the soil. This implies that all computations based upon the standard reference condition of an infinite flat plane will be too high.

(4) Under the standard reference condition, the radiation intensity at the center of a partially cleared area, decreases continuously with

altitude. In the real case, as a result of the fact that the material is not in a perfect terrain but has a finite depth, the radiation intensity first increases with altitude and then decreases as the height of the point over the cleared area is increased.

(5) The ratio of observed to calculated radiation intensities has also been found to vary with time. It was reported that in at least one case for measurements made in the Pacific, a ratio of 0.45 was found at 11 hours, 0.66 between 100 and 200 hours, and 0.56 between 370 and 1,000 hours after the detonation.

(6) According to the testimony, the influence of vegetation and trees, which could elevate some of the fallout material above the surrounding ground level, is very small when compared to radiation emanating from material on the ground. Specific corrections to allow for the presence of vegetation are not currently incorporated in estimates of the radiation intensities generated at a point as the result of fallout deposition.

(7) When the fallout occurs over a community, a number of departures from the estimates for an infinite flat plane occur. Part of the fallout that would have been deposited on the ground is, instead, deposited on the roof. This has the effect of reducing the predicted intensity by placing the source a greater distance away from the point of concern near the ground and also results in interposing material in the building structure between the fallout and the point of concern. The resulting reduction in radiation intensity was estimated to be as little as a factor of 2 in light frame residential buildings of the 1-story design, to a factor of 10 to 20 in the basements of 2-story residential buildings made of heavy material such as brick. Testimony also indicated that moderately simple protective measures such as could be provided by a combination of tables and sandbags could reduce the radiation intensities by as much as a factor of 100 in such a basement.

(8) Due to the intense scattering of both the immediate gamma radiation and neutrons from air, there is very little protection afforded to one building because it is surrounded by others. The radiation protection from that portion of the radiation dose which might come from the immediate gamma and neutron radiation would be changed by less than 50 percent due to the presence of other structures.

VII. Biological Effects

INTRODUCTION

The three basic casualty producing phenomena of a nuclear attack are (1) blast, (2) thermal, and (3) radiation. In an analysis of the biological effects of these phenomena it is necessary that they be considered singly and collectively and from the standpoint of the direct/prompt and the indirect/delayed effects.

Although it is unlikely that thermal burns, primary and secondary blast injuries, and radiation injury would occur singly in an appreciable portion of the casualties in those areas suffering heavy structural damage from weapons of any of the sizes employed in this attack, these effects were treated separately in the hearings in order that expert testimony from specialists in each field could be received.

Wherever possible, witnesses who have actively participated in human experience studies, i. e., the Hiroshima and Nagasaki surveys,

the Marshallese studies and the radiation accidents both in the United States and abroad were called.

In those areas where little or no human experience data exist, the most competent testimony, based upon extensive laboratory experimentation utilizing animals, was solicited.

BLAST EFFECTS

The biological effects of blast were considered in four categories:

(a) Primary blast effects which cause lung damage and rupture of the eardrums due to the direct effect of the pressure wave on the body. In terms of peak overpressure in pounds per square inch, nuclear weapons blasts with their relatively sustained overpressures are much more efficient producers of casualties by a factor of 10 or more than are equivalent high explosive blasts. Nevertheless, lung hemorrhage and broken eardrums were uncommon in Japan. With 1- to 10-megaton weapons lung damage would be restricted to from 2.5 to 5.5 miles, which is well within the zone of destruction of brick apartment houses (3 to 7 miles). Ruptured eardrums might occur farther out—4.5 to 7.7 miles. In other words, serious to fatal primary blast injury is unlikely to occur as an isolated event.

(b) Secondary blast effects due to flying fragments which become missiles created by the pressure wave. This pressure or blast wave would produce injurious effects by propelling loose debris, broken glass or ceramics, and building materials to a velocity high enough to penetrate the human body. This effect is important out to 5 miles from a 1-megaton surface detonation and 11 miles with a 10-megaton surface detonation.

(*c*) Tertiary effects resulting from the body itself being thrown violently by the pressure wave. Human beings may become missiles upon being picked up and hurled laterally by the blast wave. These injuries are similar to automobile and aircraft accidents, and can occur to distances of 3 to 5 miles from a 1-megaton surface detonation and 7 to 16 miles for a 10-megaton surface detonation.

(*d*) Miscellaneous injuries due to ground shock (broken legs), dust, fires created by destruction of buildings, power lines and gas mains.

It was estimated that about 5 percent of the hazard from a 10-megaton surface detonation could be related to casualties resulting directly from the pressure wave (primary effect), and that about 95 percent of the casualties would result from missiles (secondary effects) and displacement (tertiary effects). It was also pointed out that, based on "free field" effects (i.e., likened to conditions which would obtain on a perfectly flat surface) the combined effects (blast, thermal, and initial ionizing radiation) varied with weapon yield. However, the effects would be encountered in the following sequence and combinations as one moves away from the point of detonation:

	Fallout radiation	Thermal	Blast	Immediate radiation
Point of detonation	+	+	+	+
↓	+	+	+	−
Increasing distance from point of detonation	+	+	−	−
↓	+	−	−	−

Witnesses stressed the point that when a nuclear weapon is detonated in a densely populated area, a large population would be exposed to these immediate threats—blast, thermal, and immediate ionizing radiation. Dr. C. S. White summarized his analysis with this statement:

> Even without introducing thinking regarding protection, the "very close in" residual radiation levels need to be known to aid understanding and estimating the "cost" of nuclear war to a nation whose population is practically "naked" and completely unprepared and unprotected for a full scale nuclear attack.

THERMAL EFFECTS

Since thermal radiation is transmitted on a "line of sight," the vulnerability of an object or person to this effect depends on the fireball being directly visible at that point. The following major points were brought out in the testimony regarding the thermal effects of a nuclear detonation:

(*a*) Thermal radiation can cause fires by direct ignition of combustible materials, skin burns on exposed portions of the body, and temporary or permanent blindness from the intense light.

(*b*) It takes about 1 second for the thermal output from a 1-megaton detonation to reach its peak intensity, and about 3 seconds for a 10-megaton detonation. Evasive action must be taken almost instantly if it is to be effective.

(*c*) Temporary or permanent blindness could be caused by the thermal radiation if a person is looking in the general direction of the fireball at the precise moment of detonation. The lens of the eye focuses heat as well as light rays on the retina of the eye. Thus in addition to temporary or "flash" blindness of a few seconds or minutes duration from the intense light, actual burns of the retina could occur from undue amount of thermal radiation entering the eye. Neither flash blindness or retinal damage constitute major hazards during daylight because of natural restriction of the diameter of the pupil which limits the amount of light entering the eye; furthermore the blink reflex, one hundred and fifty thousandths of a second, protects the eye from undue amounts of radiation, except in those cases where the thermal pulse is delivered within extremely short times. This is the case for low-yield weapons. However, in this attack involving weapons ranging in yield from 1 to 10 megatons, the hazards of retinal damage would be negligible.

(*d*) The thermal energy falling on a unit area [13] which is required to cause flash burns was reported to be 7 to 9 calories per square centimeter to produce a second-degree burn from a 10-megaton weapon, 6 to 7 calories per square centimeter for a 1-megaton weapon, and 4 to 5 calories per square centimeter for a 100-kiloton weapon. It would take about 30 calories per square centimeter to ignite average clothing, and 5 to 10 calories per square centimeter to ignite many combustible materials such as newspaper, and cloth, with the 3-second pulse from a 10-megaton detonation.

(*e*) Under atmospheric conditions where the visibility is about 10 miles or more, thermal intensities of this magnitude can be obtained at maximum distances of 20 to 25 miles from the point of detonation. Therefore, the potentiality of mass fires (fire storms) is considered to

[13] Normally expressed in terms of calories per square centimeter.

be a major threat from the detonation of nuclear weapons in densely populated areas.

(*f*) The consensus of testimony on this subject was that the combination of blast, fire, and radiation effects from megaton-yield weapons detonated in densely populated areas would be catastrophic in nature. Normal disaster aid facilities would be completely overwhelmed. Medical facilities and supplies would be inadequate to cope with the situation. Many of the injured who could normally be saved with good hospitalization and medical care would succumb to infection and shock.

ACUTE EFFECTS OF NUCLEAR RADIATION

The biological effects of nuclear radiation differ from blast and thermal effects in that the effect of exposure may not be apparent until hours, days, or weeks following the initial injury. The most severe form of radiation injury, under conditions of nuclear war, is that resulting from exposure of the whole body to high intensity nuclear radiation originating from the detonation. The discussion in this section will consider source conditions which can create lethal external radiation exposures in 48 hours or less which would lead to visible effects on the body within a time span of hours to weeks, and which are related to problems of immediate survival.

The sources of concern are the immediate nuclear radiations consisting of neutrons and gamma radiation, "throw out" or "very close-in" fallout, and "local fallout" which is deposited many miles downwind from the point of detonation within the first few hours. "Very close-in fallout," composed of very heavy particles, is relatively unaffected by meteorological conditions. These sources are capable of creating radiation exposure conditions of 1,000 to 5,000 roentgens in a time period of from thousandths of a second in the case of neutrons to several days in the case of local fallout.

Four categories of radiation disease related to the magnitude of the dose were described. These are—

(*a*) Hyperacute response due to instantaneous radiation doses of 5,000 roentgens or greater. Irrational behavior, general collapse and shocklike symptoms develop within minutes, and terminate in death within hours. This effect is not considered significant under nuclear-war conditions since it would occur within the lethal radius of the blast and thermal effects.

(*b*) Acute gastrointestinal syndrome (a collection of symptoms) created by radiation doses of 1,000 to 5,000 roentgens. The symptoms are nausea, vomiting, fever and general fatigue starting in a few hours. Temporary recovery occurs, but the symptoms reappear in 1 to 2 weeks. Death is probably inevitable soon thereafter.

(*c*) Hematopoietic (changes in composition of the blood) syndrome which is dominant in the dose range of 200 to 1,000 roentgens. In addition to subacute gastrointestinal effects leading to nausea and vomiting a few hours after exposure, major changes occur in the composition of the blood in the period of 2 to 4 weeks after exposure. The body is particularly susceptible to infections during this time. Recovery is possible, but not at all certain. Testimony indicated that approximately one-half

of the people exposed at the level of 450 to 700 roentgens would be expected to recover if they are not subjected to additional physical stress or radiation. The other one-half would be expected to die within 2 to 4 months. The probability of recovery is, of course, greater at the lower end of the dose scale (200 to 400 roentgens).

(*d*) No obvious disease. This category is related to exposures of 200 roentgens or less. Mild symptoms of nausea and vomiting may appear, as well as later (4 to 6 weeks) changes in the blood composition. However, these people do not require hospitalization and can function normally although they may be more sensitive to later radiation exposures than previously unexposed persons.

EFFECTS OF PROTRACTED RADIATION

The residual radiation from fallout will persist with gradually diminishing intensity for months, particularly in areas where the initial level corresponded to 1,000 roentgens per hour at 1 hour after the attack. The testimony regarding the biological consequences of such protracted radiation exposure conditions emphasized the following points:

(*a*) The body can tolerate higher exposures of radiation without developing symptoms of acute radiation illness if the exposure is spread over a longer period of time. This is a factor of great importance in a post-attack situation.

(*b*) With continued or repeated exposures, biological recovery from the injury progresses with a half-time of about a month, that is, one-half recovery from remaining effects for each succeeding month, but about 10 percent of the injury is not repairable. This nonrecoverable injury builds up a pool of damaged cells in the body and contributes to very late effects, such as cancer.

(*c*) When only a part of the body is exposed, the ability to recover is increased. The radiation resistance of animals has been doubled by protecting as little as 15 percent of the body.

(*d*) Animals irradiated below the lethal level by radiation doses in excess of 100 roentgens, die at an earlier age than normal. Estimates were submitted indicating that for the survivors of a nuclear attack, 1 roentgen would shorten the life expectancy by about 10 days. However, several witnesses contended that this estimate is much too high.[14]

(*e*) Experimental studies on mice indicated that spreading an exposure of 510 roentgens over 18 days was no more injurious than spreading the same exposure over 162 days based on measurements of survival time.

(*f*) The probability of increasing the incidence of leukemia and other types of cancer was considered to be proportional to the average total radiation dose sustained by the surviving population. Potential deaths from this cause were estimated to fall in the range of about 2 percent of the deaths attributable to acute radiation injury.

(*g*) Witnesses stressed that both the dose rates and total doses used in these experiments are directly comparable to exposure conditions that would be created by the hypothetical attack situation so that

[14] Experimental evidence was cited showing that rats exposed at a dose rate of 0.1 roentgen per hour 8 hours a day for 1 year (total dose of 292 roentgens) had a longer life expectancy than their unirradiated controls. Similar observations have been reported from several laboratories.

estimates of the predicted acute effects on man can be based directly on experimental data.

SKIN BURNS FROM FALLOUT

The intensely radioactive fallout particles emit short-range beta radiations in addition to the penetrating gamma radiations. If fallout particles are lodged in direct contact with the skin, a skin burn can be created at that point. Doses in excess of 1,000 roentgens to the skin are required to produce severe burns. Good personal hygiene, by removing the fallout particles from the skin, can offset this effect. Beta burns, by creating open lesions, are easily infected. As a threat to survival, skin burns from fallout particles are much less important than the threat of whole-body gamma radiation under the exposure conditions of nuclear war. Pictures of actual skin burns on the Rongelap natives following the event of March 4, 1954, were displayed to the subcommittee during the hearings. It is significant to note that these burns were observed although the natives had been removed from the islands before a lethal dose of penetrating gamma radiation had accumulated. The testimony indicated that problems from this effect would become more significant during times of recovery when the threat to immediate survival had passed.

INHALATION HAZARD FROM FALLOUT

Little quantitative data is available on the inhalation hazard from fallout, but data from all field tests and on the Rongelap (Marshall Islanders) people as well as from inhalation experiments in animals all suggest that in a relatively heavy fallout field: (1) the dose to the lung is unimportant compared to the total body radiation from the fallout field itself, (2) the dose to the lung is less than to the gastrointestinal tract even in the absence of eating contaminated food, and (3) that the dose to the thyroid gland from the I^{131} (iodine) (because I^{131} concentrates there) could be the largest dose received by any single organ of the body, in the absence of shelter in some fallout exposure situations.

INGESTION HAZARD FROM FALLOUT

Ingestion of fallout debris could result in much larger internal radiation exposures than inhalation, yet still be of lesser concern than the external radiation for unshielded persons. During the critical weeks following the attack ingested fallout material would be almost entirely from surface contamination. The principal potential hazards from ingestion of fallout for several weeks after a nuclear detonation would be the exposure of the gastrointestinal tract itself and exposure to the thyroid gland from deposition of I^{131} therein.

Theoretical studies suggest that radiation doses to the adult thyroid may be two or more times greater than to the intestines from ingestion of fallout material during most of the critical period. However, a 1,000- to 2,000-roentgen dose to the intestines would threaten survival, whereas the adult thyroid can normally withstand tens of thousands of roentgens before serious effects occur. Children's thyroids are more sensitive and the chance of late cancer from irradiation would be

greater if the dose were received in childhood. Milk could present a special problem, since it can contain relatively large quantities of I^{131} but lesser proportions of the other fission products than present in the original fallout.

Additional testimony indicated that the accumulating deposition of radioactive elements in the human body would be comparable to the levels currently established as acceptable for occupational exposure. This source of exposure would not become a major threat to survival in the immediate postwar period.

GENETIC EFFECTS

The study of genetic effects of massive radiation on man is very limited. There is considerable evidence that the radiation exposure of a nuclear war would greatly increase genetic mutations for some succeeding generations. However, the widespread argument that the ultimate genetic consequences could lead to the virtual elimination of the human race is not supported by the testimony. The consensus of expert testimony was that the race could and would survive the type of hypothetical attack considered in these hearings, notwithstanding the inevitable costs in physical impairments and deaths due to additional genetic mutations.

An approximation was set forth by one key witness to the effect that if a portion of our surviving population had been subjected to a cumulative average exposure of from 500 to 1,000 roentgens the resulting mutations in this group would about equal in number those deleterious genes the human race already possesses.

However, it was also noted in supplementary information submitted by the OCDM at the request of the subcommittee that the average exposures to the surviving population in the United States under the assumed attack situation would be considerably less than the lower limit of 500 roentgens.

VIII. Environmental Contamination

The testimony discussed in the previous sections has dealt primarily with immediate problems related to the survival of the population resulting from an all-out nuclear attack on this country. It is the purpose of this section to examine the long-time consequences resulting from the introduction of large quantities of radioactive materials into the environment. These consequences will be considered in three categories: (1) The effect on animals, (2) the effects on food supplies, and (3) the long-term ecological[15] consequences resulting from the massive introduction of radioactive elements into the environment.

EFFECT ON ANIMALS

All domestic animals have a similar response to total body irradiation such as that encountered from fallout. Few, if any, die after exposure to 250 roentgens, and few survive a dose as high as 1,000 roentgens. The body size of the animal has little to do with its survival, although the very young or the very old may be more sensitive.

[15] Ecology deals with the biology of the mutual relationships between living organisms and their environment.

The principal facts related to this topic are summarized in the following points:

1. There is no single clinical reaction for irradiation damage in animals. Complete collapse of the burro to an acute exposure in low lethal range is unique but may be observed in most other animals if high exposure doses are given rapidly. Following an exposure there are usually days of good health, this is followed by 4 or 5 days of apathy, followed by increased irritability, hyperesthesia, decreased food and water intake, and finally death or recovery. Animals usually die or recover within 3 or 4 weeks. There is always a latent period between irradiation and death.

2. The characteristic blood picture of the irradiation syndrome in animals is immediate decrease in numbers of white blood cells; a lesser and slower reduction and faster recovery of red blood cells; a slower clotting time and impaired clot retraction. Leukemia has been observed following total body irradiation of swine.

3. The immune response of animals to parasites and disease is affected by total body irradiation. Active immunities have been completely destroyed, however the response to the immunity of viruses, toxins, or bacteria is not always similar.

4. There are no distinctive effects of irradiation on the reproductive system. Doses in the lethal range are necessary to impair fertility. Lower exposures, at the proper time in gestation, may cause fetal aberrations. Genetic changes will not necessarily be deleterious due to the common practice of selective breeding.

5. Particulate matter in fallout has lodged sufficient radioactive material in the coats of grazing animals close to nuclear detonations to produce beta burns in the hides. These lesions are characterized by atrophy of the skin or necrosis depending upon the severity. They may heal completely, leave a smooth, weakened skin with discolorized hair, or form permanent scar tissue. Experimentally it takes thousands of roentgens of beta radiation to cause a beta burn. None of the animals, accidentally exposed and observed has had other physical signs of exposure.

6. Limited experimental evidence and field testing indicate that animals in the path of a fallout which fail to develop beta burns will have been exposed to less than harmful external radiation and the radionuclides from that cloud will be practically innocuous to the grazing animal.

Animals that sustain exposure intense enough to produce beta burns but live longer than 3 weeks or a month fall into the same category as those without burns.

All other grazing animals will have received a fatal total body exposure dose and both external beta irradiation and irradiation from ingested sources are of no consequence.

7. It is theoretically possible to produce an area of high radiocontamination by overlapping nonsimultaneously arriving fallout. In such a case there would be no beta burns on the hide of animals but deaths would be due to total body irradiation from ground concentrations or the ingested mass. Otherwise, the radiocontamination will be of little consequence to the animal.

8. It is suggested that the limiting factor for survival following a nuclear attack will be man and not the animal. The use of animals and animal byproducts may reduce the hazard of radiocontamination

following nuclear warfare below that which must be tolerated if food is obtained directly from plants. Although total body irradiation and intestinal doses from absorbed isotopes will be much higher for animals, their relative faster maturity and reproductive cycle will compensate.

EFFECT ON FOOD SUPPLIES

The postulated nuclear attack would have very significant effects on the agricultural and food resources in the United States. Those agricultural resources within the range of the immediate effects from blast and thermal radiation would, of course, be vulnerable to destruction. The extent to which fie would be swept by the wind beyond the immediate circular area related to the point of detonation of the weapons was not estimated quantitatively in these hearings. Growing agricultural crops of almost any variety would be expected to be somewhat more vulnerable to the effects of the thermal flash and resultant fire than to the effects of the blast wave.

By contrast, virtually the entire region east of the Mississippi River would be affected to some degree by local fallout resulting from this particular hypothetical attack. The following information was developed in the testimony with respect to the consequences following such deposition:

1. On the mid-October date assumed for the simulated attack, the harvest would have been completed for a number of major agricultural crops, including oats, barley, rye, rice, peaches, winter wheat, tobacco and nearly complete for hay, vegetables, dry beans, and spring wheat. Crops which would be in about the middle of the harvest period include corn, soybeans, apples, pears, grapes, grain sorghum, cotton, and flax. Crops which would not have been harvested include citrus fruits, fall potatoes, sugarcane, and peanuts.

2. The uptake of radioactive isotopes would be most significant for those crops which had not yet been harvested.

3. Iodine 131, iodine 133, and cesium 137 may be readily absorbed directly by leaves and would be the principal isotopes taken up during the early period by plants. Strontium 89 and strontium 90 are absorbed relatively rapidly from the soils and would be taken up at a somewhat slower rate. Other materials such as zinc 65, cerium 144, ruthenium 106, promethium 147, and plutonium 239, are absorbed in amounts ranging generally from one one-thousandth to one-tenth that of strontium 90.

4. The radioactive elements in the heavy local deposits are usually soluble to the extent of 3 percent of the total material, or less. (See sec. VI.) Within the limits determined by the change in solubility as a function of particle size and hence of distance from the point of detonation, the mechanisms of uptake of radioisotopes resulting from fallout deposition in the attack are the same as those described in connection with the mechanisms of uptake of materials derived from the weapon testing program. (See summary report of May hearings.[16])

5. The principal barriers to the recovery of growing agriculture crops would be shortage of fuel and machinery, and radiation hazard to workers. It was the consensus of the testimony that deliberate exposure of workers to radiation in order to save contaminated crops

[16] Fallout From Nuclear Weapons Tests, Summary—Analysis of Hearings, May 5–8, 1959.

would in general not be warranted, unless such food was absolutely essential to survival.

6. The deposition from worldwide fallout would be expected to lead to environmental contamination at a level about 20 times that which has resulted from the weapon-testing program. This level of contamination under the conditions of dire emergency associated with a nuclear attack would not be sufficient to mitigate against the use of such food in the immediate postwar period.

7. Foods which have been harvested could have been subjected to contamination on the outside. If the fallout particles are removed, the food may be considered as essentially "uncontaminated" from the environmental radioactivity viewpoint.

8. Decontamination of land was recommended only for areas having a very high availability of strontium 90, since other isotopes have either short half lives or have a low uptake by plants.

9. In general, if the external gamma radiation level permits the growing, harvesting, and processing of foods, the corresponding threat from radioactivity in food would not impair survival and recovery from the attack.

Testimony regarding the effects on processed and stored foods brought out the following points:

1. Food items stored within a region subjected to blast and thermal damage might be slightly radioactive as the result of activation by neutrons. It would, however, be safe to eat them within a week.

2. There is no significant reduction in the wholesomeness of food subjected to nuclear radiation. This includes effects on vitamins and chemical changes affecting taste and odor.

3. Food containers are, generally, more resistant to blast than are the structures in which they are housed.

4. Processed food, under cover, is not directly affected by fallout. Any deposit on the outside of the container can be easily removed, and with reasonable care in handling the packages, will not get into the food itself. Therefore, processed foods in cans or glass would be the preferred items of diet immediately following a nuclear-attack situation.

LONG TERM ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

One popularly held belief in the public mind is the idea that all-out nuclear war would render a country uninhabitable for many years. For the hypothetical attack considered by the subcommittee the consensus of the testimony on this point indicated that, although the shock could be severe, life would continue and that full ecological recovery would eventually occur.

It was pointed out that immediate effects, particularly from fire, could trigger longtime processes that result in environmental changes of long duration, and therefore changes in the biotic composition of species that could live under the changed conditions. If fire were to denude wide areas of forests and vegetation, the land would become subject to erosion from wind, rain, and snow. New dust bowls might be created.

In areas of severe fallout, unprotected animals, particularly mammals, would sustain severe losses. Whether the areas affected would be extensive enough to significantly affect the natural balance of the

biotic community was not estimated, although the opinion was expressed that if the natural balance among animal species was seriously altered over an extensive area, one of the major postwar problems would be combatting the many insects which are much less subject to radiation effects than mammals.

The consensus of the testimony was that these long-range effects can be considered only in general qualitative terms at the present state of knowledge. This limitation is primarily important to quantitative evaluations of ultimate cost related to a particular attack level, and does not alter the conclusion that survival and recovery are possible after such an attack.

IX. Survival Measures

INTRODUCTION

The assumption of our attack pattern is based on the capability of an enemy to deliver 1,446 megatons of nuclear weapons on U.S. targets, notwithstanding the resistance of our military defensive forces. In such a case the problem of protecting the civilian population goes beyond the preventive power of military defense forces and becomes a responsibility of nonmilitary preparation and organization. This we ordinarily refer to as "passive" or "civil defense."

Our present civil defense activity is based on Public Law 920, 81st Congress, enacted early in 1951, before the development of the hydrogen bomb. The first hydrogen device (preceding actual hydrogen weapons) was exploded in November 1952. This new development in the art brought with it revolutionary problems in military and civilian defense. Public Law 920, geared as it was to the prehydrogen weapon age, placed the operating responsibility for civil defense solely on the State and local governmental bodies. Only minor amendments, policywise, have been made since 1951. There has been only a nominal change from sole responsibility of local governments to joint responsibility between the Federal and local governmental bodies. This joint responsibility has not been clearly defined. The estimated casualties from the assumed hypothetical attack are based on the present state of civil defense protection.

It is not the purpose of the subcommittee to pass judgment at this time on the responsibility for planning and funding an effective national civil defense program. The bulk of the testimony was directed toward the development of information which would delineate the effects of a nuclear war on our civilian population and their environment. The problem of survival of civilian populations faced with the threat of nuclear war and the decision as to whether the Federal Government, the State, or the individual pays the bill remains and demands solution.

These facts indicate the path toward the goal of an effective national civil defense program.

The estimates of casualties that might be anticipated as the result of the hypothetical nuclear attack assumed that the preparation of our people was as it stands today, and that a part of the attack was directed against our major centers of industry and transportation. The consensus of expert witnesses was that the major centers of popu- ion are more vulnerable to the immediate effects of blast and ther- radiation than to fallout. However, it was also pointed out that

in the event of an attack directed mainly or exclusively against military installations, the resulting fallout would present a serious hazard to densely populated areas hundreds of miles from the targets.

Although the overall problems of national military and civil defense were not within the scope of the hearings, the subcommittee considered that a true picture of the biological and environmental consequences of nuclear war could not be developed without summarizing the technical possibilities dealing with the basic problem of survival for our people.

PROBLEMS RELATED TO A NATIONAL SYSTEM

Protection against fallout is considered the first requirement for protection against the effects of nuclear weapons. It was estimated that about 20 percent of the population would experience fallout levels that would correspond to the condition represented by 3,000 roentgens per hour based on the standard reference time of 1 hour after detonation.[17] From data similar to that presented in section VI, it was shown that this condition would lead to a radiation exposure of about 12,000 roentgens in the first year, and that 10,000 roentgens of this would be encountered in the first 2 weeks.

The basic radiological defense system, derived from the radioactive properties of the fallout material, was proposed to provide three phases:

Phase 1.—Emergency phase where protection from the massive doses of radiation encountered at relatively early times is the major problem. Adequate shelter to provide shielding against the nuclear radiation is considered the only technically feasible answer to this problem.

Phase 2.—Recovery phase when exposure in the open for short times is possible. Advantage is taken of this condition to start reclaiming critical facilities which are necessary for recovery. Removal of the offending debris (decontamination) is considered the most important technical approach when the process of radioactive decay is not sufficient.

Phase 3.—Final recovery to provide for the basic problems of public health and safety when the gamma radiation has decreased to negligible proportions. In the absence of other standards applicable to wartime conditions, a gamma radiation level of 0.3 roentgen per week (the maximum peacetime radiation rate for occupational exposure) was suggested to define this condition. The consensus appeared to be that much larger concentrations of radioisotopes such as strontium 90 and cesium 137 could be tolerated under these conditions than would be considered acceptable in times of peace.

The interrelations between the efficiency of shielding during the emergency phase, the efficiency of decontamination during the recovery phase, and the resultant expected radiation doses absorbed by the population are shown in table IX–1.

[17] This is called the standard intensity.

TABLE IX-1.—*Survival arithmetic*

[Heavy fallout area: 3,000 roentgens per hour at 1 hour]

	Roentgens
Dose during 1st year	12,000
Dose during 1st 2 weeks	[1] 10,000
Dose between 2 weeks and 1 year	[2] 2,000

Shelter shielding factor	Emergency dose	Reduction factor	Operational recovery dose
	Roentgens		*Roentgens*
10	1,000	10	200
100	100	100	20
1,000	10	1,000	2
10,000	1		

[1] Emergency phase: 10,000 roentgens.
[2] Operational recovery phase: 2,000 roentgens.

This table shows that for the fallout condition used—

(1) A shielding factor of 10 is inadequate since a radiation dose of 1,000 roentgens is lethal.[18]

(2) A shielding factor of more than 1,000 is not profitable since 10 roentgens is less than 10 percent of the dose required to cause direct casualties. This implies acceptance of the corresponding nonrecoverable biological effects.

(3) A shielding factor of 100 would be adequate if the initial fallout level corresponded to a standard intensity of 300 roentgens per hour at 1 hour instead of 3,000 roentgens per hour at 1 hour.

Different combinations of useful radiological defense systems which relate different combinations of shielding effectiveness, stay time in the shelter, reclamation effectiveness, and radioactive decay properties are summarized in table IX-2.

TABLE IX-2.—*Useful radiological defense systems*

[Heavy fallout area: 3,000 roetgens per hour at 1 hour]

System No.	Emergency phase countermeasures	Operational recovery phase countermeasures	Dose during 1st year (roentgens)
1	6-month shelter with 0.01 residual number	None	320
2	6-month shelter with 0.001 residual number	None	210
3	2-week shelter with 0.01 residul number	0.1 reclamation	300
4	2-week shelter with 0.001 residual number	do	210
5	2-week shelter with 0.01 residual number	0.01 reclamation	120
6	2-week shelter with 0.001 residual number	do	30

Other factors relating to a national system may be summarized as follows:

(1) The need for a formal radiological defense system disappears at fallout levels less than a standard intensity of 100 roentgens per hour at 1 hour. The protection afforded by existing buildings is generally adequate for this condition.

(2) Most buildings offering a shielding factor of 100 or more are located in metropolitan centers and will be vulnerable to the effects of blast and fire if that area is a target.

[18] A *shielding factor* of 10 is provided in the basement of some two-story homes. See "The Effects of Nuclear Weapons," p. 404. The corresponding *residual number* which relates the dose in the unprotected condition to the dose with the countermeasure is 0.1.

(3) Where such protection does exist, additional provisions for ventilation, food and sanitation would have to be made.

(4) Very good protection can be provided by underground shelters. The best information available is for a particular design based on a 24- by 48-foot ammunition-storage magazine [19] buried under 3 feet of earth. This shelter was occupied by technical personnel at Operation PLUMBOB [20] at a distance of somewhat less than 1 mile from a 17-kiloton detonation. A documentary film shown at the hearings gave an impressive demonstration of its effectiveness.

(5) The USNRDL shelter provides for 100 people at an estimated cost of $100 to $125 per person sheltered. It provides a shielding factor for radiation of 1,000 or more, and protection against blast at a level of 10 pounds per square inch. Protection against mass fires can also be provided.

(6) The USNRDL shelter can be designed for protection against a blast pressure of 35 pounds per square inch. Availability of such protection under conditions of the subcommittee's hypothetical attack could reduce the fatalities from approximately 25 percent of the U.S. population to about 3 percent. All of these would result from the immediate blast effects—no deaths from either thermal or nuclear radiation being anticipated under these conditions.

(7) The cost of providing protection for 200 million people at the levels prescribed by the higher performance defense system was estimated as between $5 billion and $20 billion, depending on the use made of existing facilities. This cost is almost entirely in the shelter phase, since reclamation competence is largely a matter of training and organization.

(8) The main conclusion presented to the subcommittee was that the country must have a national radiological defense system if the Nation is to withstand and recover from an attack of the scale which is possible in an all-out nuclear war.

In addition to data on group-type shelters, the subcommittee also received testimony on techniques of adapting present buildings for shelter purposes and proposals for individual family shelters.

Information bearing on these points may be summarized as follows:

(1) Techniques for estimating the degree of protection that can be obtained from existing buildings have recently been developed.

(2) On the first floor of a two-story wood building, the radiation was estimated to average about one-half of that outside. On the first floor of a brick building, it was one-seventh.

(3) Closing openings in basements with bricks or sandbags will reduce the radiation in the basement by a significant amount.

(4) Radiation dose rates inside fireplaces and behind masonry chimneys are lower than those in the center of the room.

(5) A heavy table covered with 7½ inches of concrete block and placed in the corner of a basement will reduce the radiation dose rate by a factor of 200 to 1,000 over that observed on the ground outside the structure.

(6) Prototype models of a combination transistorized portable radio and radiation detection unit were demonstrated at the hearings. This concept of a "citizen's instrument" is known as the "Banshee" because

[19] This is basically a prefabricated building of the type known as a quonset hut.
[20] This test was conducted by the U.S. Naval Radiological Defense Laboratory under the sponsorship of the Atomic Energy Commission.

the output from the radiation-detection unit is converted to a wailing signal which is amplified through the loudspeaker of the radio. Such a device when the radio is operating, gives clear warning of the presence of significant amounts of fallout.

(7) A new pamphlet has been issued by the OCDM which gives complete specifications for an individual family fallout shelter.

A considerable body of civil defense information has been developed by the Department of Defense, the Office of Civil and Defense Mobilization, and the Atomic Energy Commission. Shelter-design studies and evaluation tests have been conducted, decontamination and fallout monitoring techniques and equipment have been developed, and studies of weapons effects and various aspects of fallout have been undertaken.

In addition, the OCDM has conducted numerous exercises, including its annual Operation Alert, to determine the effectiveness of civil defense doctrine and operations under hypothetical attack conditions.

All of the data developed by these agencies is available for use in formulating a national civil defense program of the type suggested in the testimony presented at the subcommittee hearing. The present study, as well as other congressional investigations, such as those conducted by the Military Operations Subcommittee of the House Committee on Government Operations indicate the need for an improved and more effective national program of civil defense.

ADDENDUM

A Digest of Testimony on Strategic Considerations

INTRODUCTION

The discussion of survival measures in the body of this report related to the technical aspects of achieving various degrees of protection from the effects of nuclear weapons. The subcommittee's purpose in soliciting expert testimony on that subject was to provide an up-to-date public record of available data which are believed to be pertinent to a full consideration of the effects of a possible nuclear war. The subcommittee did not undertake to establish a case for or against any particular plan of protection or specific civil defense measures. Such an undertaking was not within the scope of the subcommittee's inquiry.

By the same token, the subcommittee did not endeavor to examine current national security and foreign policy with a view to formulating alternatives or recommending changes in existing policy. However, the data presented to the subcommittee with respect to the immediate and protracted effects of nuclear weapons may have far-reaching strategic implications deserving most careful consideration by the executive branch and the Congress.

For this reason, the subcommittee presents in the pages which follow a digest of testimony concerning the major strategic implications arising from the basic calculations presented at the hearings. Mr. Herman Kahn of the Center of International Studies, Princeton University, made the main presentation on this subject and was followed by a review panel of other principal witnesses. [1]

"BALANCE OF TERROR" CONCEPT

The subcommittee was told that recent calculations tend to cast doubt particularly on the widely held notion that nuclear weapons have created a "balance of terror." This theory holds that a thermonuclear war would mean the certain and automatic annihilation of both the antagonists and that it might possibly mean the end of civilization. To some, this concept of a "balance of terror" means that wars will be avoided, if it is assumed that no sane man would initiate a war in which there could be no victor. Thus, it is said, the very violence of nuclear weapons will eliminate war from the world entirely.

There are also other major implications of this theory. If both sides can utterly destroy the other, preparations to reduce casualties and lessen damage will be of no avail and there is no need to shoulder the financial burden of such preparations. Some people have carried

[1] It may be noted, incidentally, that Mr. Kahn testified that the calculation of effects presented to the subcommittee were very similar to those made by Mr. Kahn and his associates at the Rand Corp. 2 years earlier, though they were made independently and without reference to the data developed by the Rand Corp.

this argument even further. They have agreed that modern weapons are so enormously destructive that a very few of them would suffice to deter the enemy and that it is therefore possible to deter war with much smaller deterrent forces than we have provided in the past.

A very similar debate apparently took place in the Soviet Union several years ago. One witness testified that in 1955–56 Malenkov agreed that nuclear war would mean the end of civilization, the Soviet Union could afford to reduce both their investment in heavy industry and their military expenditures and concentrate on consumers' goods. Khrushchev and the Soviet military took the opposite position and in general their view seems to have prevailed.

The subcommittee was told that although thermonuclear war would be horrible in the extreme it would not necessarily mean the total destruction of both sides and that the "balance of terror" theory may be in error. In terms of immediate casualties in the United States, specialists testified that in the hypothetical attack specified, about 30 percent of the American population would be killed. This assumed only very primitive measures to protect the general population and, although there was no attempt to examine what would have happened if, for example, the attack had come after a period of international tension providing time for people to get out of target areas or if adequate shelter protection had been provided, the testimony indicated that to the extent that advance measures had been taken the casualties would have been greatly reduced. It was stated that studies by the Rand Corp. have indicated that with certain advance measures, the United States might well be able to recover almost completely from such a disaster in about 10 years.

It was stated that although the long-term genetic effects of radioactive fallout would be severe, these effects would be spread out over hundreds of years. Even though the total is large, the percentage of people affected in any one generation would be small and it is doubtful if the possibility of damage to 1 or 2 percent of future generations of his own population could by itself operate as a deterrent to a determined enemy.

THE FIRST-STRIKE ADVANTAGE

It was indicated that the degree of damage one side or the other suffers will depend very much upon the circumstances in which the war occurs. The attacker has enormous advantages. He chooses the time and method of attack, presumably exploiting any possible weaknesses in the other's defense. The defender must strike back *with a damaged force,* piecemeal and without coordination, in the teeth of *a fully alerted air defense system,* and against *an enemy population that has taken at least minimum precautions.* Without considering classified information, it is very difficult to estimate how much damage the attacker would suffer, but some of the testimony indicated that it would be significantly less than that estimated for the damage on the United States in the hypothetical attack considered.

The conclusion submitted to the subcommittee by one witness was that the United States cannot rely on an automatic "balance of terror" that could be maintained by minimum retaliatory forces with no protection provided for the civilian population. Adequate deterrence, it was said, can be maintained only by providing, first, a

force that can absorb an enemy blow and still strike back with adequate strength and, second, certain minimum nonmilitary protection for the civilian population.

TYPES OF DETERRENCE

It was also stated that even if the "balance of terror" theory were correct, the United States would still be faced with important strategic problems. As the witness pointed out, in 1914 and 1939, it was the British and the French who declared war on the Germans and not vice versa. It is difficult for Americans to realize that, under certain circumstances, neither the Soviets nor the Europeans might believe that the United States would come to the aid of Europe. In making this point, the witness asked the subcommittee to ponder a hypothetical situation in which American defenses were so weak and Soviet retaliatory forces so strong that if the United States responded to a Soviet ground attack on Europe the Soviet counterretaliation would kill all 177 million Americans. Under such conditions, the witness said, it would not be surprising if neither the Europeans nor the Soviets found the U.S. promise to come to the aid of Europe credible. But if it is true that the Soviets and the Europeans would not believe that we would honor our commitments to our allies if it meant 177 million American deaths, what level of casualties do they believe we would accept? It was stated that, to the extent that the Soviets believe we can keep our casualties to a level we would find acceptable, whatever that level may be, they will be deterred not only from attacking the United States directly, but also from very provocative aggressions, such as a ground attack on Europe. But, it was said, to the extent that they do not believe we can keep casualties to an acceptable level, the Soviets may feel safe in undertaking these extremely provocative military adventures.

In discussing this aspect of the strategic problem facing the United States, the witness distinguished between what he called Type I deterrence and Type II deterrence. Type I deterrence, which the British call "passive deterrence" on the assumption that it requires no act of will to initiate a response, is the deterrence of a direct attack. If the United States were directly attacked, its response would be automatic. Type II deterrence, which the British have called "active deterrence" is defined as the forces necessary to deter an enemy from engaging in military adventures short of a direct attack on the United States itself. There is a question as to how effective nuclear retaliatory forces would be as a Type II, "active" deterrent. In pondering this question, it must be assumed that before launching on such an extremely provocative adventure, the enemy would have alerted his own retaliatory forces and instituted protective measures for his population. By such precautionary measures, the Soviets, according to the witness, might limit casualties to 10 percent of its population and one-third of its wealth. This is just about what they suffered in World War II, from which they had recovered by 1951. If the Soviets believed that they could limit destruction to this extent and were also convinced that the United States had failed to take the measures that would similarly limit destruction in the United States, they might well feel free to launch an aggressive attack.

RELATIVE VULNERABILITY OF THE UNITED STATES AND THE SOVIET UNION

There was no testimony to indicate that U.S. defenses were so weak or Soviet forces so strong that the hypothetical situation described above would soon become a reality. On the other hand, one witness testified that if the current rates of Soviet and American progress in long-range delivery systems continues relatively the same, and if current American air and civil defense programs remain basically unchanged, a situation might well arise in the future in which neither the U.S. Type I or Type II deterrence would be effective.

A clear advantage was attributed to the Soviet Union with respect to relative vulnerability to the effects of a possible nuclear war. The Soviet Union, for example, has only 50 million people in its 135 largest cities, while 42 million Americans are concentrated in our 12 largest metropolitan areas, with 12 million in the New York metropolitan area alone.

The testimony indicated that, given the aggressor's advantage of forewarning, it is not inconceivable that the Soviet Union could achieve an 80 percent evacuation of its target areas, leaving only 10 million persons in concentrated target cities. Moreover, it was stated that recent studies of Soviet civil defense indicate that a substantial program was recently instituted to train the entire Soviet population in basic survival techniques. However, it is understood that prior to 1958 the Soviet program was not geared to thermonuclear weapons.[2]

In the United States the situation is vastly different, as a number of witnesses pointed out. In contrast to the Russian people, Americans are almost totally unfamiliar with what would be required of them under conditions of a possible nuclear war. There is no experience, such as the Soviet people have undergone, of having risen from the ruins of wartime destruction to a pinnacle of postwar power. Finally, of course, there is no comprehensive program for protecting the American people in the event of a nuclear war, a program which, as Dr. Libby said, should "tell the people what they may be up against" and what must be done.

Various witnesses indicated that this is a lack which can prove very dangerous for the success of American and western policy against Communist aggression. For it is apparent from the testimony of these hearings that the total unreadiness of the American people to survive a nuclear war—a state said to be well known both to the Russians and to our allies—can greatly undermine our capability to resist possible Soviet "nuclear blackmail." As the subcommittee was told:

> The possibility that if you cannot accept the Russian retaliatory blows, and it is clear to the Russians and the Europeans and you that you cannot accept it, you may be in a very, very sad position. * * *

But the testimony indicated that it is not too late to take measures to correct this weakness. As already indicated in the preceding section of this report, fallout protection would have saved the approximately 22 million radiation casualties resulting from the hypothetical attack on the United States.

[2] "Civil Defense in Western Europe and the Soviet Union," report of the Military Operations Subcommittee of the House Committee on Government Operations, H. Rept. No. 300, 86th Cong., 1st sess., April 1959.

Put another way, the subcommittee was told, a very moderate shelter program, which would combine protection against fallout and some blast resistance, could reduce the expected casualties to approximately one-third of those who would die if there were no protection at all. A more extensive program, designed to protect persons in our urban areas, could reduce the overall fatalities of this attack from 25 percent of the population to approximately 3 percent.

Such measures were believed not to be terribly expensive. The subcommittee was told that the program of fallout shelters, which would go far toward saving the lives of the 60 percent of all Americans who do not live in or near target areas, is one which depends on simple tools and simple techniques. The lives of millions could be saved or lost by a simple choice. Thus, one eminent witness pointed out that on the basis of the 1954 thermonuclear detonation at Bikini, where the area of blast and thermal effects was perhaps 300 square miles (a circle with a radius of 9¾ miles), the total area of likely radiation casualties was approximately 7,000 square miles. Clearly, the subcommittee was told, it is the people in the intermediate 6,700 square miles about whom something could be done: "We can save them easily; we can lose them easily."

The burden of the testimony received on this point was that if such protective measures were taken, the impact of America's ability to survive a nuclear war would be so great that the likelihood of such a war would be vastly reduced. So long as the Soviets have the advantage of forewarning and can reduce their already low vulnerability through a comprehensive civil defense program, the United States will be at a marked disadvantage. Its firm foreign policy will be open to doubt and disbelief, and to possible blackmail.

Thus, it was suggested that our lack of a civil defense program could lead the Soviets to take a provocative step which we could not ignore, and a nuclear war would have started with no protection for the American people. Or, as a final paradox, the subcommittee was told, in a world of great tension the Soviets may be unable to believe that we would allow an aggressor to strike us first, which the theory of "massive retaliation" implies. The acceptance of such a military disadvantage as a basis for our national policy may seem foolish to them. They may therefore discount the sincerity of our position and expect instead that the United States actually intends to strike the first blow. A war which neither side wanted could thus break out because of our defensive weakness.

APPENDIX

Glossary of Terms

Alpha particle	A fundamental particle resulting from radioactive decay, consisting of 2 protons and 2 neutrons and possessing kinetic energy or energy of motion. The energy of an alpha particle is measured in million electron volts. Abbreviated: Alpha.
Average or mean life	The actual life of any particular radioactive atom, can have any value between zero and infinity. The average or mean life of a large number of atoms, however, is a definite quantity and is equal to 1.44 times the half life.
Beta particle	A fundamental particle resulting from radioactive decay. It consists of a negatively charged electron possessing kinetic energy or energy of motion. Beta particle energies range from kilo electron volts to million electron volts. Abbreviated: Beta.
Biological half life	The biological half life of any element or radioactive nuclide is the time interval required to reduce the number of atoms present in the body to half of their initial value. The biological half life does not include the radioactive half life of a radioactive element.
Curie	That quantity of a radioactive nuclide disintegrating at the rate of 3.70 by 10^{10} atoms per second or 2.22 by 10^{12} atoms per minute. Abbreviated: c.
Micromicrocurie	1 million millionth of a curie or that quantity of a radioactive nuclide disintegrating at the rate of 3.7 by 10^{-2} atoms per second of 2.22 atom per minute. Abbreviated: $\mu\mu$c.
Millicurie	1 thousandth of a curie or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{7} atoms per second or 2.22×10^{9} atoms per minute. Abbreviated: Mc.
Megacurie	1 million curies or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{16} atoms per second or 2.22×10^{18} atoms per minute. Abbreviated: Mc.
Dose	The radiation delivered to a specified area or volume or to the whole body.
Effective half line	The time required for a radioactive element in the body to be diminished to half of its value as a result of the combined action of radioactive decay and biological elimination.

Electron volt---------------------- A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Larger multiples of the electron volt are frequently used, viz, Kev. for thousand or kilo electron volts; Mev. for million electron volts; and Bev. for billion electron volts.

Erg------------------------------ Unit of work or energy done by a unit force acting through unit distance. The nuclear unit of work or energy is the Mev. which is equal to 1.6×10^{-6} ergs.

Gamma ray----------------------- Electromagnetic radiation resulting from radioactive decay. Gamma rays have no mass and no charge, but have energy which ranges from Kev. to Mev.

Half life-------------------------- The half life of a radioactive atom is the time interval over which the chance of survival is exactly one-half. In any large number of disintegrating radioactive atoms half of the atoms present at any time will decay during one-half life. The half life for a particular nuclide is given by

$$t½=\frac{0.693}{\lambda}$$

where λ is a constant for each nuclide.

Biological half life------------- The biological half life of any element or radioactive nuclide is the time interval required to reduce the number of atoms present in the body to half of their initial value. The biological half life does not include the radioactive half life of a radioactive element.

Effective half life-------------- The time required for a radioactive element in the body to be diminished to half of its value as a result of the combined action of radioactive decay and biological elimination.

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$$t½: \frac{0.693}{\lambda}$$

where λ is a constant for each nuclide.

Stratospheric half life---------- The time interval required to reduce the activity present in the stratosphere to half by removal from the stratosphere to the troposphere. Stratospheric half life does not include radioactive half life of any of the radioactive nuclides.

Isotope--------------------------- An isotope is the individual species of atoms in an element having a certain mass. For example: U^{233}, U^{234}, and U^{235} are isotopes of uranium.

Kilo electron volt---------------- See electron volt.

Mean or average life — The actual life of any particular radioactive atom can have any value between zero and infinity. The mean or average life of a large number of atoms, however, is a definite quantity and is equal to 1.44 times the half life.

Megacurie — 1 million curies or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{16} atoms per second or 2.22×10^{18} atoms per minute. Abbreviated: Mc.

Micromicrocurie — 1 million millionth of a curie or that quantity of a radioactive nuclide disintegrating at the rate of 3.7×10^{-2} atoms per second or 2.22 atoms per minute. Abbreviated: $\mu\mu c$.

Millicurie — 1 thousandth of a curie or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{7} atoms per second or 2.22×10^{9} atoms per minute. Abbreviated: Mc.

Million electron volts — See electron volt.

Nuclide — A nuclide is the individual species of atoms in an element having a certain mass and a specific energy content. Therefore, more than 1 nuclide may compose an isotope. For example, Ba–137m (radioactive) and Ba–137 (stable) are nuclides of the same isotope.

Rad — The unit of absorbed dose, which is 100 ergs per gram. The rad is a measure of the energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. It is a unit that was recommended and adapted by the International Commission on Radiological Units at the Seventh International Congress of Radiology, Copenhagen, 1953.

Relative biological effectiveness — The ratio of gamma or X-ray dose to the dose that is required to produce the same biological effect by the radiation in question.

REM — Roentgen equivalent man: that quantity of any type ionizing radiation which when absorbed by man produces an effect equivalent to the absorption by man of 1 roentgen of X- or gamma radiation (400 KV).

REP — Roentgen equivalent physical: the amount of ionizing radiation which will result in the absorption in tissue of 83 ergs per gram. (Recent authors have suggested the value of 93 ergs per gram.)

Stratosphere — The upper portion of the atmosphere, above (11 km), more or less (depending on latitude, season, and weather) in which temperature changes but little with altitude and clouds of water never form, and in which there is practically no convection.

Stratospheric half life — The time interval required to reduce the activity present in the stratosphere to half by removal from the stratosphere to the troposphere. Stratospheric half life does not include radioactive half life of any of the radioactive nuclides.

Strontium unit — Formerly sunshine unit. 1 thousandth of the maximum permissible body level of Sr-90. It is equal to 1 micromicrocurie per gram of calcium.

Tropopause — The imaginary boundary layer dividing the upper part of atmosphere, the stratosphere, from the lower part, the troposphere. The tropopause normally occurs at something like 35,000 to 55,000 feet altitude, although it depends on season and location.

Troposphere — All that portion of the atmosphere below the stratosphere. It is that portion in which temperature generally rapidly decreases with altitude, clouds form, and convection is active.

End.